INSTITUT DE LA VIE

Proceedings of the World Conference

TOWARDS A PLAN OF ACTIONS FOR MANKIND

VOLUME 1

LONG RANGE MINERAL RESOURCES AND GROWTH

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FOREWORD

The aim of the INSTITUT DE LA VIE is:

— to start a permanent train of thought, both basic and applied, theoretical and practical, about life and the human condition, whether considering our species within the biosphere or mankind in all its dimensions;
— to bring together the highest authorities in science and technology in order to seek constantly, among the plurality of disciplines and of philosophies, the solutions that would best suit the needs and yearnings of human beings and so to assist in their decision-making those who are invested with the greatest responsibilities;
— to set up permanent exchanges between men at all levels in order to make them sensitive to the value of life and teach them how to respect it.

The INSTITUT DE LA VIE organized, from 9th to 14th September, 1974, a world conference on:

"TOWARDS A PLAN OF ACTIONS FOR MANKIND:
NEEDS AND RESOURCES, METHODS OF FORECASTING"

Participants to this conference were 236 belonging to 29 countries.

Five items were chosen, they were each subject to a preparatory colloquium in September and October 1973. The works of this colloquium were published in the book: "TOWARDS A PLAN OF ACTIONS FOR MANKIND, PROBLEMS AND PERSPECTIVES".[1]

The proceedings of the conference itself are published in five volumes.

This event will be followed by numerous others, prompted by the same will to carry on the human adventure and to enable man to live and to achieve himself.

The INSTITUT DE LA VIE will sustain the same joint effort of universal concertation every four years.

The INSTITUT DE LA VIE is the meeting-point of anxieties, hopes and determination. Here consciousness is aroused, the alert given. It is vigilant at the outposts of the preservation of life. It establishes the equations of the future and of salvation. To awaken consciousness is to create confidence as all despair is henceforth void of effect. Confidence in our ability to find new solutions to new situations, confidence in mankind, confidence in its spirit, confidence in life.

M. MAROIS

[1] North-Holland Publishing Company, 335 Jan Van Galenstraat, P.O. Box 103, Amsterdam-W, The Netherlands, M. MAROIS, editor, 1974, 558 pages.

PRÉFACE

L'INSTITUT DE LA VIE a pour objet:

— d'engager d'une manière permanente une réflexion fondamentale et appliquée, théorique et pratique, sur la vie et la condition humaine, qu'il s'agisse de notre espèce dans la biosphère ou de l'homme dans toutes ses dimensions;
— de rassembler les plus hautes compétences scientifiques et techniques pour rechercher à chaque instant dans le pluralisme des disciplines et des philosophies les solutions les mieux adaptées aux besoins et aux aspirations des humains et d'aider ainsi la décision de ceux qui se trouvent investis des plus hautes responsabilités;
— d'établir un courant d'échanges entre les hommes à tous niveaux pour les sensibiliser à la valeur de la vie et les éduquer à la respecter.

L'INSTITUT DE LA VIE a organisé, du 9 au 14 septembre, 1974, une conférence mondiale sur le thème:

"VERS UN PLAN D'ACTIONS POUR L'HUMANITE:
BESOINS ET RESSOURCES - METHODES DE PREVISION"

à laquelle ont participé 236 personnalités appartenant à 29 pays.

Cinq thèmes ont été choisis qui ont fait chacun l'objet, en septembre et octobre 1973, d'un colloque préparatoire. Les travaux de ces colloques ont été publiés dans l'ouvrage "VERS UN PLAN D'ACTIONS POUR L'HUMANITE - PROBLEMES ET PERSPECTIVES".[1]

Les actes de la conférence elle-même sont publiés en cinq volumes.

Cette manifestation sera suivie de nombreuses autres inspirées par la même volonté de poursuivre l'aventure humaine et de permettre à l'homme de vivre et de s'accomplir.

L'INSTITUT DE LA VIE soutiendra tous les quatre ans le même effort concerté de réflexion universelle.

L'INSTITUT DE LA VIE est le point de rencontre des inquiétudes, des espoirs et des volontés. Il est le lieu de la prise de conscience, de la mise en alerte. Il veille aux postes avancées de gardien de la vie. Il pose les équations de l'avenir et du salut. Prise de conscience, prise de confiance puisque tout désespoir est désormais porteur de néant. Confiance dans notre capacité de trouver des solutions neuves à des situations neuves, confiance dans l'homme, confiance dans l'esprit, confiance dans la vie.

M. MAROIS

[1] North-Holland Publishing Company, 335 Jan Van Galenstraat, P.O. Box 103, Amsterdam-W, The Netherlands, M. MAROIS, editor, 1974, 558 pages.

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for their material and moral support which has made this conference possible.

Chapter I

RESOURCES AVAILABILITY AND DEPLETION

CONTENTS

OUVERTURE

H. Brown

I am chairing this session dealing with mineral source availability and depletion. During the course of the post-war years we have seen what I have liked to call the fissioning of humanity into two cultures: the culture of the rich and the culture of the poor. The culture of the rich embraces something like 930 million persons; the rate of population growth is low and decreasing corresponding to about 0.8 of a percent per year at the present time, but the affluence of the people who live in this culture is increasing extremely rapidly and indeed most of the material resources in the world today which are consumed are being consumed by the people in the rich nations. The culture of the poor embraces some 2800 million persons, the rate of population growth is high—about $2\frac{1}{2}\%$ per year—and it is still increasing. We can get some idea as to what we mean by rich and poor by looking at any one of several indicators—steel consumption per capita, energy consumption per capita, gross national product per capita. In the case of steel, the average person in a rich country consumes about 600 kilograms of steel per year. The average person in a poor country consumes about 20 kilograms of steel per year; the difference between them is a factor of 30. At the same time, the rate of consumption of steel in both rich countries and poor countries is increasing at the same rate, about 6% per annum. If current trends prevail, in the next 50 years, there will then be 10,000 million people in the world, 85% of whom will be poor. I think we must ask a number of questions in this session. First how affluent will the rich countries become? Will affluence continue to grow indefinitely in the future? Will the population of the poor countries continue to grow as rapidly in the future as they are growing today? Where will the needed raw materials come from? What proportion will come from recycling? What proportion will continue to be provided by nature?

There are two important aspects of raw materials now being used by man today. For the most part they are not evenly distributed; in large measure they exist in the poor countries and are processed in the rich ones. What difficulties will this situation present in the years ahead? We have already seen rebellion in the Middle East with respect to petroleum. Venezuela has announced that it will in the future discontinue iron ore shipments to thc United States and it has expressed its intention to develop its own integrated steel industry for which their iron ore will be the raw material. Competition among the rich nations over the relatively high-grade resourccs is a source of danger in the future.

The second aspect of our mineral resources is that we are called upon to process ores of steadily decreasing grade. How far will this trend carry us? What will thc cost be? Can we ever hope to reach the point where most nations can achieve some semblance of self-sufficiency? These are critical problems and I hope that in the course of our deliberations during this session we can obtain some insights as to how solutions might be approached. I hope further that concrete actions can be recommended. With that I would like to call upon Dr. Sheldon to make a few brief introductory remarks.

INTRODUCTION

R. P. Sheldon

I am Richard Sheldon and have been essentially the organizer of this session on resource availability and depletion. The session is divided equally into three parts. The first will be the description and analysis of the mineral resources in the crust of the Earth; formal papers will be presented by V. E. McKelvey and P. E. Cloud and discussions will be led off by C. Ruiz and R. Weber. The second session will be on the following topic: The investments that are required to win these minerals from the crust of the Earth. Formal papers will be presented by J. P. Gautsch and D. Sikka and discussions will be led off by B. Bercè. Then the third part of the session will deal essentially with projections of future primary mineral supply. V. E. McKelvey will now present the opening statement.

POTENTIAL WORLD MINERAL RESERVES

V. E. McKelvey

Director, U.S. Geological Survey

An expert has been described as one who is seldom right but never uncertain. On the subject of the magnitude of world potential mineral reserves, I may very well qualify as an expert under the first half of that definition, but I do not qualify under the second part, for it is a matter about which I am very uncertain indeed. There are two things about potential reserves, however, that I am certain of: one is that they are larger than those we are presently able to identify, and the other is that, however large they may be, they will not support exponentially increasing consumption indefinitely.

Minerals and mineral fuels are literally the keystones of the modern world. Their expanding use since the Industrial Revolution has supported both a remarkable expansion of world population and a rising level of living, even in the less-developed countries. Whereas the renewable resources once sustained world populations of scores of millions of people, minerals and mineral fuels now support billions of people and they are dependent on continuing supplies of these resources for their very existence. If, as some believe, potential reserves of key minerals and fuels are sufficient to meet demands for only a few scores of years or so, we should immediately seek measures to shift toward a way of life and a socio-economic system suitable for far lower levels of mineral and fuel consumption. On the other hand, if we knew we had larger potentials, we would have more time to taper off on exponential growth and arrive at levels of consumption sustainable into the more distant future. The question of the adequacy of potential supplies is a highly controversial one, of course, with opposing views ranging from almost immediate doom to cornucopia forever, but I want to emphasize that the complexity and importance of the problem are not only worthy of the controversy but of the extensive work required to resolve it.

A few basic concepts should be understood before discussing the problem further. One is the distinction between reserves and resources. We count as reserves those deposits that have been identified and that are presently producible under present economic and technologic conditions. Resources broadly defined include such deposits; they also include deposits too lean or inaccessible now to be producible commercially but that may become usable with advancing technology or higher prices; and resources also include undiscovered deposits of both minable and unminable quality. We thus distinguish between the birds in the hand, which we can count, and the birds in the bush, about which we [illegible]-thesize and speculate.

Another fundamental concept that must be understood is [illegible] come into being. Put in the simplest terms, it is God [illegible] is man that creates resources, defined as natural su[illegible]

man. Man does this by a variety of processes—finding uses for minerals and rocks that were not usable before, learning how to search profitably for undiscovered deposits, how to mine and process materials that could not be recovered previously, how to substitute abundant for scarce materials, and achieving similar advances that make it economic to use materials that were not usable previously. In addition to creating resources, man is also able to extend their life by increasing the efficiency of their use, by recycling used materials and reducing waste, and by conservation in use.

It is the very nature of these processes that introduces much of the uncertainty that I spoke about at the outset. Our knowledge of the earth at this point is vast by comparison with earlier times but it is minuscule when it comes to an understanding sufficient to delineate all the geologic environments that contain usable resources. And even if it were adequate to do that, we still would not know our full potential because we cannot predict the extent of the advances that may come in materials science and technology which may make it possible to utilize resources not usable now. Nor can we predict the extent to which we may be able to extend the life of resources through the process I described, although we can be certain that we can be far more efficient in our use of both energy and minerals than we have in the past.

I said we could be certain that our potential reserves are larger than those we can now identify because I think we have had enough experience to know that human creativity is a continuing process, just as certain to continue as are other natural processes. I have not the slightest doubt that this process is going to enlarge our potential reserves and our resource base in ways we cannot visualize now.

It is surely this same confidence that leads some to believe in cornucopia forever. But whereas I am sure many neo-malthusians consider my own views too optimistic, I swing toward the limits-to-growth advocates when it comes to such ideas, simply because they do not take account of the effects of continued exponential growth. I may illustrate the limits involved succinctly by saying that a one billion year supply of anything measured at present rates of world consumption would be exhausted in 582 years if consumption continued to grow at 3% a year—as it has for many commodities in recent decades. And just to underscore this point, a two billion year supply would be consumed in one more doubling time of 23.5 years. Of course, consumption of a finite supply would not follow such a pattern of increase to its final exhaustion, but the point is that level of consumption is just as significant an element in the life of a supply as the magnitude of the resource, and exponential growth in consumption can quickly exhaust even a huge supply. Without elaborating on this subject, I may say that I believe the problems we are having with shortages of energy and some other minerals are in large part a result of demand overtaking our abilities to develop supply, with consumption at the high levels it has now reached. It is indeed time to seek other means than simple growth in material consumption to advance the welfare of man.

Returning to the subject of potential reserves, difficult as it is to appraise their magnitude, it is important to try, for even though we can assume that our best estimates are probably wrong, it is valuable to know what we have in the hand and what we think we can find in the bush.

Included for distribution with this paper are two tables, Table 1 consisting of estimates of world production, reserves, and resources of selected commodities, prepared by various methods by the authors of U.S. Geological Survey Professional Paper 820, and Table 2 showing what might be called theoretical estimates of potential reserves prepared by Ralph

Erickson on the basis of the relationship between reserves and crustal abundance that I determined some years ago.

I will not discuss these estimates in detail, but a few generalizations are significant. One is that the estimates from Professional Paper 820 show that for nearly all the minerals listed there appear to be known resources adequate to meet world needs at present rates of consumption for only a few decades to a century or more. Estimates of the magnitude of undiscovered resources have not been made for many minerals, mainly because of a lack of a suitable methodology to make them in the light of available geologic knowledge. But for most of the minerals for which estimates of undiscovered resources have been attempted, the estimates are about equal to known resources or are larger only by a factor of 2 or 3. Placed against the buzz-saw of continued exponential growth, these estimates give no grounds for complacency about the adequacy of resources that we know and that we can hypothesize and speculate about to meet long-term world needs for mineral resources.

The theoretical approach Erickson and I have taken is based on the fact that the United States' reserves of base and precious metals long sought are in rather similar proportions to their crustal abundance. The assumption that this relation applies approximately to other elements makes it possible to estimate the magnitude of recoverable resources of other elements. Taking lead as the basis of extrapolation, Erickson uses a factor of 2.45×10^6 the crustal abundance of the elements (in parts per million) as the basis for postulating presently recoverable resources in the United States and multiplies by 17.3—the ratio of the world land area and that of the United States—for world estimates. Estimated in this manner, world recoverable resources of most minerals are theoretically many times larger than known reserves. Presently subeconomic resources are not included in these estimates, and those that may be brought within economic reach by changes in technology or economic conditions would enlarge the estimates shown. So too would whatever subsea resources become available, for these estimates apply to the land only.

With our present state of knowledge one cannot have great confidence in these theoretical estimates, especially as applied to specific elements, but they suggest that there are recoverable resources beyond those we can see and imagine now and that for many minerals they may be large, large enough to support consumption at present levels far into the future. Essential in providing such additional supplies is the development of knowledge that makes it possible to find concealed deposits, to utilize lower grade and presently refractory materials, to substitute abundant for scarce materials, and to extend the resources we have and find by improving recovery in mining and processing, by recycling, by improving the efficiency of use, and by reducing waste and improving conservation in use. Some of these steps, such as recovery of lower grade ores, may involve increased use of energy and some, such as achieving more conservative use, may be difficult to achieve for other reasons. But these are the steps by which to create and extend resources for the future, and they need to be vigorously pursued.

No amount of success in these efforts, however, will support continued exponential increase in consumption, and it is time for developed countries to begin searching for means to taper off the present rate of increase while still improving the level of living of impoverished people through increased efficiency in resource use.

TABLE 1. World production, reserves and resources of selected commodities

	Estimated production 1973	Known resources: Reserves	Known resources: Identified subeconomic resources	Undiscovered resources: Hypothetical resources	Undiscovered resources: Speculative resources	Units	Remarks
Aluminium	69.5 mil lt	15	10			bil lt	Bauxite only
Antimony	78 th st	5.6		1.6		mil st	In Pb–Ag–Zn–Cu deposits
Arsenic	47.5 th st		17.6	14.3	Small	mil st	As As_2O_3
Asbestos	4.5 mil st		75	37		mil st	Chrysotile, No. America only
Barite	4.3 mil st		310	400	1280	mil st	
Beryllium	160 st		100	650		th st	Mostly non-pegmatitic
Cadmium	18.2 th st	3	15.5			mil st	
Chromium	6.9 mil st	1.6	2.6	3.6+		bil lt	Shipping ore and concentrate
Cobalt	28.1 th st		4.8			mil st	Not including sea nodules
Copper	7.7 mil st	344	381+	400	320	mil st	
Fluorspar	5.2 mil st		190			mil st	Crude ore 3/1 to processed ore
Gold	43.5 mil troy oz	1	1			bil troy oz	
Iron	810 mil lt	252	530			bil mt	
Lead	3.8 mil st	140	1500			mil st	
Lithium	3.4 th st		4.5	6.5		mil st	
Manganese	23.5 mil st	6.5	7.7	10	Large	bil st	Ore-type material
Mercury	270 th f		7.1			mil flasks	76-lb flasks @ $400
			17.0			mil flasks	76-lb flasks @ $1,000
Molybdenum	158.5 mil lbs		63			bil lbs	
Nickel	717 th st		2			bil st	Av. 1% Ni, sulfide ore
			7			bil st	Av. 0.2–1% Ni Lateritic
Niobium	26.5 mil lbs	14	equal to reserves			mil st	
Phosphate	108 mil st	6		9	About nil	bil st	Greater than 24% P_2O_5
Platinum metals	5.2 mil troy oz		424			mil troy oz	
Silver	299 mil troy oz	5.4				bil troy oz	
Tantalum	1.3 mil lbs	72	equal to reserves			th st	
Tin	240 th lt	9.9	10.1	9.2	7.5	mil lt	
Titanium	3.7 mil st	about 2		1.6		bil st	
Tungsten	44.5 mil st	230				mil st	In units of WO_3
Vanadium	25 mil lbs	10.4				mil st	
Zinc	6.1 mil st	235	1300	3600		mil mt	

TABLE 2
Potential world recoverable resources*

	Recoverable resource potential (metric tons $\times 10^6$)	Ratio of potential to present reserves
Antimony	19	5
Beryllium	64	4000
Bismuth	0.12	1.5
Cobalt	763	360
Copper	2120	10
Gold	0.15	14
Lead	550	1000
Lithium	933	1200
Mercury	3.4	30
Molybdenum	46.6	23
Nickel	2590	38
Niobium	848	unknown
Platinum	1.2	133
Selenium	2.5	36
Silver	2.75	18
Tantalum	97	354
Tellurium	0.015	0.3
Thorium	288	288
Tin	68	12
Tungsten	51	42
Uranium	93	112
Zinc	3400	42
	(metric tons $\times 10^9$)	
Aluminum	3519	3000
Barium	17	223
Chromium	3.26	47
Fluorine	20	600
Iron	2035	23
Manganese	42	67
Phosphorus	51	34
Titanium	225	2000
Vanadium	5.1	500

* Drawn from Ralph L. Erickson, Crustal abundance of elements, and mineral reserves and resources, in U.S. Geological Survey Professional Paper 820, pp. 21–25, 1973.

Proposition submitted by Dr. Vincent E. McKelvey

1. Developed countries should aim toward reducing their rates of increase in consumption of minerals, water, and mineral fuels, and seek to support further economic advancement through increased efficiency in the production and use of these vital materials.
2. Governments and intergovernmental bodies should endeavor to raise the level of living of impoverished people, in both poor and rich countries, through improved means of the distribution of income, efficiency in use of resources, and other means that do not increase world consumption of minerals, water, and mineral fuels.
3. Governments and intergovernmental bodies should vigorously encourage the processes and activities by which resources are created and extended, as through scientific research, exploration, prevention of waste, recycling, and conservation in use.

Governments, intergovernmental bodies, and the peoples of all countries should strive to prevent further growth in world population and to bring world population into equilibrium with the earth and man's supportive capabilities.

Governments, intergovernmental bodies, and private institutions should dedicate themselves to the advancement of the knowledge and skills of the people of the world in order to enhance their abilities to utilize the earth's resources efficiently and wisely, to maintain a safe and satisfying environment, and to enhance the quality of life for present and future generations.

Governments and intergovernmental bodies should take steps to appraise potential resources and to examine possibly imbalancing resource, environmental, and population trends in order to anticipate and avoid chaotic consequences of resource development and of economic and population growth.

COPPER RESERVES AND POTENTIAL COPPER RESOURCES IN THE PORPHYRY COPPER METALLOGENIC PROVINCE OF CHILE

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The aim of this report is to make a preliminary estimation of the copper reserves and potential copper resources of Chile. The justification for the presentation of this contribution in a Colloquium devoted to analyzing the Long-range Mineral Resources of the World is because copper is one of the more intensively used metals in the industrialized world, and Chile, as is well recognized, has the greatest copper resources in the world. Therefore, a well-founded evaluation of the copper resources of Chile would be of much help in the determination of the worldwide occurrence of copper. Inasmuch as most of the copper resources of Chile are contained in porphyry copper deposits, the evaluation of this type of deposit would give a reasonably true figure of the total amount of copper which is present in the country. Furthermore, the fairly regular distribution of copper over large volumes of host rocks makes these types of deposits more amenable than others for the calculation of ore reserves and potential ore resources.

THE PORPHYRY COPPER DEPOSITS OF CHILE

Most of the porphyry copper deposits of Chile are distributed in a narrow longitudinal belt located on the western slope of the high Andes at altitudes varying between 1000 meters and 4500 meters. This belt, which constitutes the main porphyry copper metallogenic province of Chile, has been found to extend, in an approximate north–south direction, from the Chile–Perú border in the north (latitude 18°S) to approximately latitude 39°S; this represents a length of 2300 kilometers. To the north of the Chile–Perú border, the same belt extends far up to the northern border of Perú.

All of these deposits are in close spatial and genetic relation with Tertiary intrusive porphyries of mesosilicic composition. Between 30 km to 50 km west of the axis of the belt that contains the main deposits appears to be another lineation of porphyry deposits and related hydrothermal developments that contain the Andacollo deposit; this lineation, little explored until now, is probably genetically related to intrusives of Late Cretaceous age.

The porphyry copper deposits in actual or past exploitation are those of Chuquicamata, El Teniente, El Salvador, Potrerillos, Andina, Disputada, and Andacollo. This list includes the two largest copper deposits of the world, El Teniente and Chuquicamata, each one containing reserves of several thousands of millions of tons of ore. Besides the above-mentioned

deposits there are many others which are in different stages of exploration; this group includes the deposits and prospects of Mocha, Cerro Colorado, Quebrada Blanca, El Abra, Pampa Norte, Sierra Gorda, Sierra Jardín, and Los Pelambres.

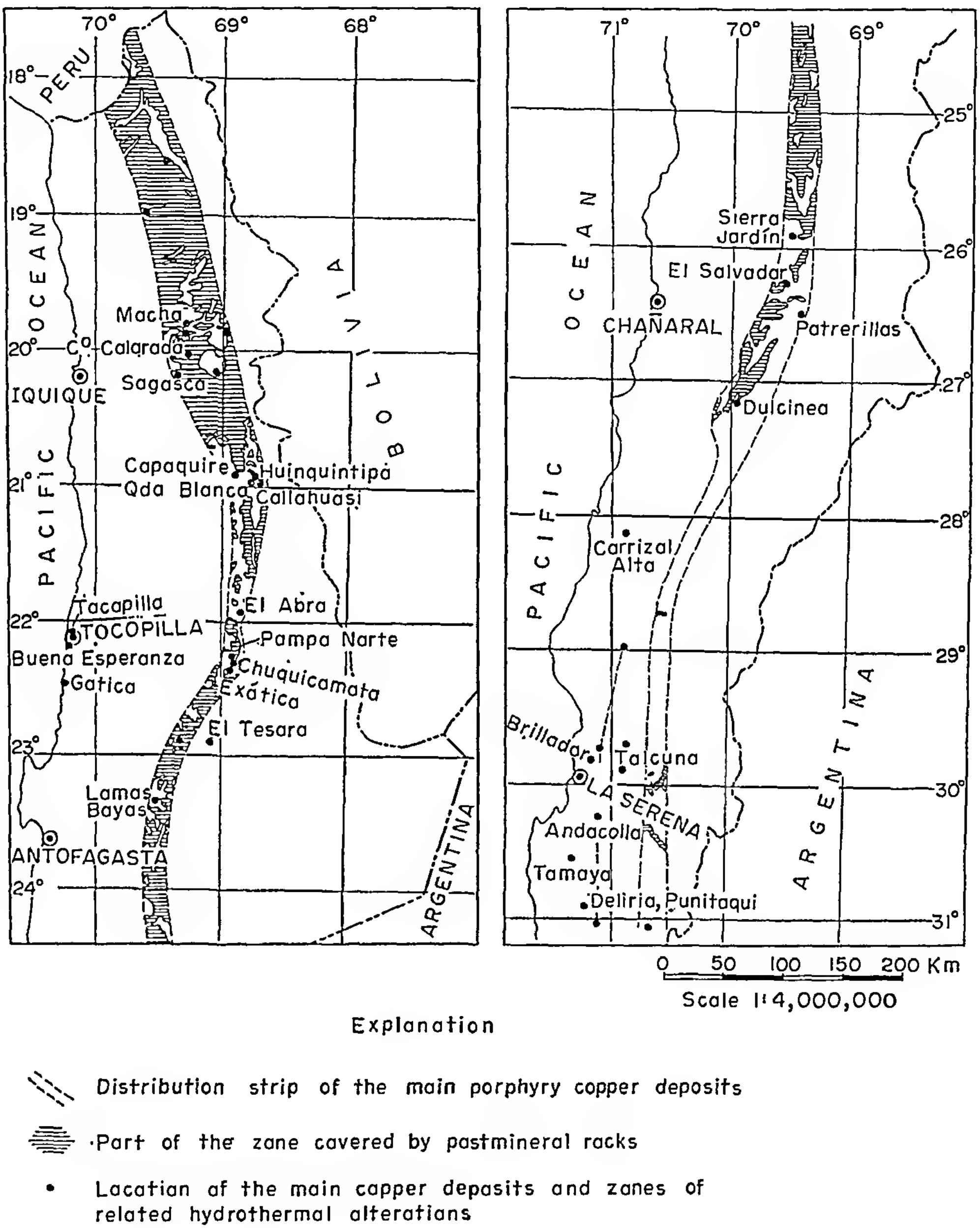
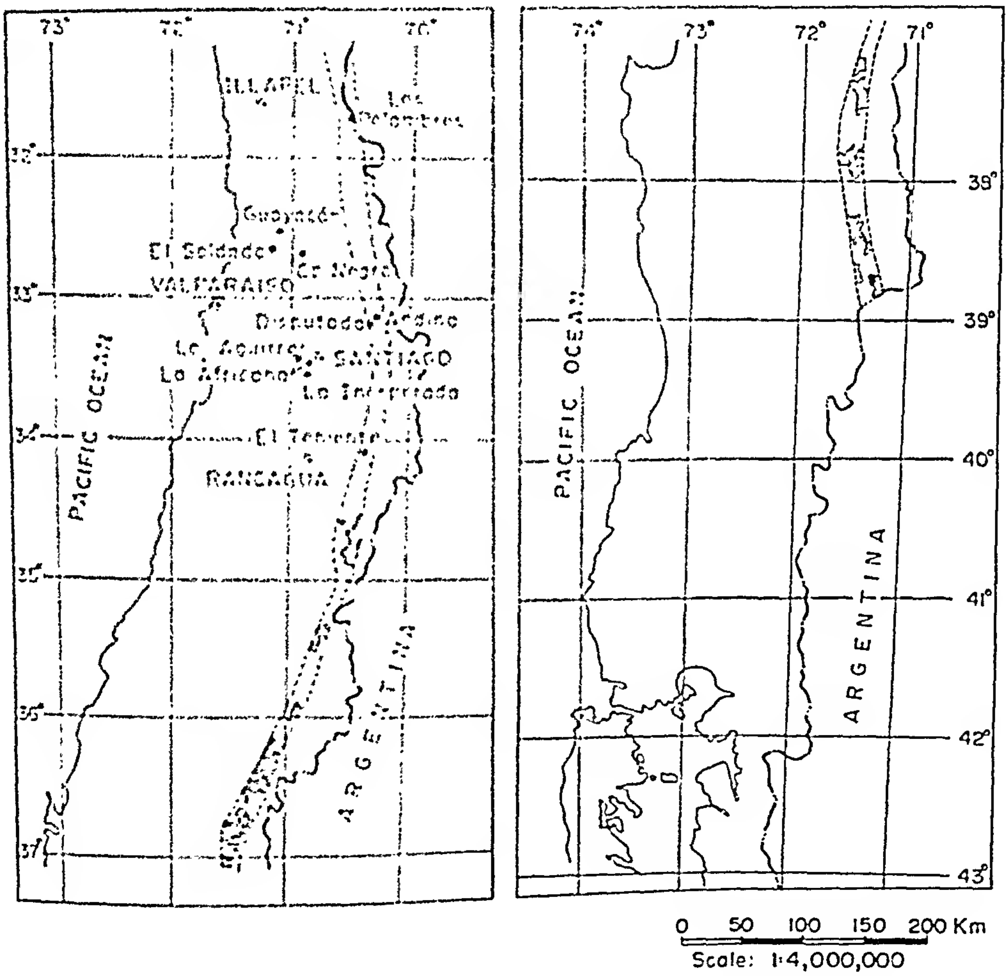


Fig. 1

The most specific feature of the porphyry copper deposits is that they correspond to large volumes of mineralized rocks, showing great extensions in three dimensions, these varying between hundreds of meters and several kilometers. The largest dimensions in known Chilean deposits are found at Chuquicamata and El Teniente. The orebody of Chuquicamata

is oval shaped with a major axis of 3600 meters and a maximum width of 800 meters. Exploratory work has demonstrated that the vertical extension of mineralization is of more than 1000 meters. At El Teniente, the mineralized body is roughly circular, with diameters varying between 1500 meters and 2500 meters and the known vertical extension is of more than 1200 meters. In relation with the vertical depth of the porphyry copper columns, a matter very pertinent to the problem of resources evaluations, Lowell and Guilbert (1970) have stated that these columns may extend vertically up to 3000 meters. Applying the model developed by the above-mentioned authors to the known Chilean porphyry copper deposits, it seems very likely that the exposure levels in these deposits vary between the most upper part to the middle part of the column.



Explanation

Distribution strip of the main porphyry copper deposits

Part of the zone covered by postmineral rocks

• Location of the main copper deposits and zones of related hydrothermal alterations

The Tertiary porphyries related with the porphyry copper deposits in most cases intrude volcanic rocks, although some intrude granitic rocks. In either cases the host rocks of the porphyries are of Mesozoic to Early Tertiary age. Post-mineral volcanic and sedimentary rocks of Late Tertiary or Quaternary age cover part of the area occupied by the main porphyry copper belt, eventually burying undiscovered deposits. In the northern half of its length, between 40% and 70% of the area is covered by the post-mineral rocks and in about 40% of the whole area of the metallogenic province, the pre-mineral rocks do not outcrop.

COPPER RESERVES AND RESOURCES IN THE CHILEAN PORPHYRY COPPER DEPOSITS

In the evaluation of the Chilean porphyry copper reserves and resources we will follow the concepts and terminology adopted by the Bureau of Mines and the Geological Survey of the U.S. Interior Department (U.S. Geol. Survey Prof. Paper 820). Accordingly, we divide the resources in *identified resources* and *undiscovered resources.*

Identified resources are specific bodies of mineral-bearing rock whose existence and location are known. This category includes *reserves,* masses of mineralized rock whose extent and grade are known to a greater or lesser degree and which can be extracted at a profit with existing technology and at present price levels. Reserves can be divided in turn in measured, indicated, and inferred. Measured reserves are the materials that are computed from analysis and measurements of well-located samples. Indicated reserves are those computed partially from sampling and partially from geological projections. The sum of materials in both measured and indicated resources are called demonstrated reserves. Inferred reserves is the material in unexplored but identified deposits, for which estimates of quality and size are based on geologic evidence.

Identified-subeconomic resources are deposits not now exploitable economically. In turn, these resources are divided in Paramarginals and Submarginals, representing successively lower degrees of economic recoverability. It is important to point out that the distinction between reserves and identified subeconomic resources do not depend only on the availability of existing technology and on the price levels, but also on previous experiences in organization and productivity. For example, in Chile some ores have been until now considered paramarginals, whereas in some other circumstances and countries they might be considered as reserves.

The *undiscovered resources* are divided into two informally designated categories. Hypothetical resources are defined as undiscovered resources, which may reasonably be expected to exist in a known mining district. Speculative resources are undiscovered materials that may occur in known types of deposits in a favourable geologic setting where no discoveries have been made.

Computations have been made on the copper resources contained in most of the known porphyry copper deposits and prospects of Chile. These computations are based on the information gathered from the Geologic Divisions of the largest porphyry copper mines in operation (Chuquicamata, El Teniente, Andina, El Salvador, and Exótica*), from geologists in charge of exploration of developing mines (El Abra, Pampa Norte, Andacollo, Sierra Jardín, and Los Pelambres) and finally from geologic reports of several prospects (Mocha, Quebrada Blanca, and Cerro Colorado).

* Exótica is a secondary copper deposit derived from the Chuquicamata deposit.

The bulk results are summarized in Tables 1 and 2.

TABLE 1. Reserves
Identified economic resources
(metric tons)

Demonstrated	Inferred	Total		
Tons of ore	Tons of ore	Tons of ore	Average grade % Cu	Fine copper contained
6012,000,000	3253,000,000	9265,000,000	1.02	94,500,000

Identified subeconomic resources
(under conditions existing until recently)
(metric tons)

Paramarginal			Submarginal			Total	
Tons of ore	Aver. grade % Cu	Fine copper contained	Tons of ore	Aver. grade % Cu	Fine copper contained	Tons of ore	Fine copper contained
1970,000,000	0.51	10,030,000	4625,000,000	0.24	10,870,000	6595,000,000	20,904,000

TABLE 2. Undiscovered resources hypothetical
(metric tons)

Tons of ore	Estimated grade	Fine copper contained
4500,000,000	0.76	34,200,000

The figures given in Tables 1 and 2 may be compared with the total copper production of the country, to date, which is estimated to be in the area of 26 million tons of fine copper.

It should be pointed out that these computations of copper reserves and resources in the known porphyry copper deposits and prospects may be considered conservative for the following reasons:

(a) In the operating mines, the resources have been computed to comparatively shallow depths varying between 400 meters up to 1200 meters. This leaves out deeper, but equally large, volumes of mineralized rocks corresponding to the categories of inferred reserves and/or of hypothetical resources.

(b) In most of the mines and prospects in actual exploration, the little information currently available does not permit the evaluation of the complete potential of these resources.

The area occupied by the main porphyry copper metallogenic province of Chile is far from been completely prospected and explored, leaving many undiscovered deposits to be found in the future.

Hypothetical Resources outside of the known Deposits and Prospects of the Main Porphyry Copper Province, and estimation of ultimate resources of the said province

In the first place, as it was stated above, 40% of the area of the said metallogenic province is covered by post-mineral rocks, leaving probably approximately the same percentage of the total copper resources of Chile as undiscovered buried deposits. But, on the other hand, possibly part of these undiscovered deposits may have an overburden which is too thick to be economically exploited at this time.

In the 60% of the uncovered area of the porphyry copper metallogenic province, it can be stated, as a very rough estimation, that more than half of it has not been even reasonably prospected.

In accordance with this reasoning, the resources computed in the known deposits and prospects, which are about 150 million tons of fine copper, are contained in approximately one-third of the whole area of the porphyry copper provinces. As mentioned before, part of the covered area may contain non-commercial deposits, but on the other hand the amount of resources computed in the known deposits is a conservative figure. Therefore, it is justified to establish as a preliminary estimation that the ultimate copper resources of the Chilean porphyry copper provinces are approximately 450 million tons of copper, of which 100 million tons are reserves.

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PRESENTLY AVAILABLE RESERVE AND RESOURCE ESTIMATES AND PRECISION AND ACCURACY OF MINERAL RESOURCES ESTIMATES

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Population growth, higher demands for civilization, and industrial development have increased the needs of mankind rapidly and, thereby, increased the per capita use of many raw materials. The rise in consumption has been faster in the last decades than during any other period in history. For this reason, the problems of the world's future mineral and energy supply must be investigated. These studies, which are conducted by numerous scientists in the world, lead to estimates about the life of resources. Bases for such estimates are data about measured and indicated reserves, actual production and consumption rates, and trends in production and consumption.

The results of some investigations about the world's future mineral and energy supply have been published. They were a shock in industrialized countries because they indicated lives of less than 20 years for some essential elements (mercury, tin, and zinc, for example). This catastrophic outlook about the future supply of some important metals raised the question about the accuracy of such resource estimates.

ACCURACY OF RESOURCE ESTIMATES

All estimates about the time of mineral depletion have to consider that we shall never arrive at figures about reserves and consumption sufficiently definite to find out the fatal moment at which everything will be exhausted. For this reason all estimates are rather doubtful. This appears most clearly if we compare the data published in 1952 in the "Paley Report" with the data available today. In this report, a complete picture was given of the production, consumption, and reserves of various raw materials in the year 1950 both for the U.S.A. and for the rest of the world. Also given were estimates for 1975 of production and consumption of the same areas. A comparison between the Paley Forecast for 1975 and corresponding figures for 1972 (Metallgesellschaft A.G.) is very instructive (Table 1). The over-estimates of U.S. consumption for 1975 in the Paley Report and the under-estimates of the consumption in the Western world other than the U.S.A. is apparent. Another estimate, the world production of lead metal between 1950 and 1973, shows a similar situation. The lead production in 1973 was 52% higher than the world reserves of lead calculated in 1950 (31% for the Western countries and 218% for the East-block

countries). Also the reserves of lead metal calculated in 1973 are greater than the reserves of 1950 and the total world production between 1950 and 1973 combined.

TABLE 1. U.S. minc-production, U.S. consumption and Wcstern-world consumption (cxccpt U.S.A.) of copper, lcad, and zinc for 1950 (Palcy Report), 1975 (Paley forecast), and 1972 (Mctallgesellschaft A.G.)
(in 1000 metric tons of metal)

Copper	1950	1975	1972
U.S. mine production	823	725	1490
U.S. consumption	1570	2300	2023
Western-world consumption (except U.S.A.)	1219	1872	4170
Lead			
U.S. mine production	390	270	561
U.S. consumption	1100	1770	1300
Western-world consumption (except U.S.A.)	766	1360	2210
Zinc			
U.S. mine production	560	630	437
U.S. consumption	1048	1440	1300
Westcrn-world consumption (except U.S.A.)	983	1546	3445

An old Chinese proverb says: "To prophesy is extremely difficult—especially with respect to the future", which is valid also for resource estimates because of the presence in such forecasts of unknown factors whose magnitude cannot be taken in account.

One of these factors is the possibility of discovering *new mineral deposits* on the continents. Formerly geologists discovered such mineral accumulations simply by eye and hammer. Improvements in exploration technology together with better geological knowledge led recently to discoveries which could not be expected some decades ago. The application of remote sensing methods and modern geochemistry and geophysics opened ways of exploration for the deposits which were hardly recognizable at the surface. This exploration technology will be continuously improved, making possible the discovery of additional resources.

Another important factor is the *exploitation of low-grade ore deposits.* The exact figures of the total resources of low-grade ores in the world are not known. The increasing demand on primary material and the danger of depletion of the known mineral deposits will raise the trend to exploitation of low-grade ore. This trend is obvious, for example, in copper mining where the limits of pay decreased from 5.2% in the year 1800 to less than 0.5% at present.

With regard to Germany there is sufficient quantity of low-grade iron ore. However, production had stopped due to the availability of high-grade iron ore on the world market. Nevertheless, low-grade ore represents an enormous reserve for future times or in shortage situations. Such low-grade iron ore reserves are known from many other industrialized countries.

The increasing production of lower-grade ores requires new technologies and more

energy and adds to the danger of environmental pollution due to greater quantities of mineral waste.

One factor of uncertainty in resource estimates is the possibility of exploiting deposits in areas with *insufficient infrastructure*. But we have to consider that, in the near future, the infrastructural conditions in the Arctic, for example, will become more favourable for exploration and exploitation. Climatic conditions which formerly represented an obstacle for both have already been overcome. What actually remains are the difficulties in access and road building and the high transportation costs. With increasing prices of raw materials, these difficulties can be easily governed by adequate technology. But it is clear that the inclusion of such resources in our estimates yields only a short-term effect. For long-term estimates they are of less importance.

One of the most striking events in the field of resources was the discovery of *mineral accumulations on the sea floor and along the coasts*. In the sea we find various elements in the water, in the sediments, and in concretions.

Important elements in *seawater* are Cl, Na, and Mg (> 1 g/l) and S, Ca, K, Br, C, Sr, B, Si, and F (> 1 mg/l). Only Mg, B, and Cl (as NaCl) are economically extracted today. The possibility of extracting gold from seawater was demonstrated by the German chemist Haber. In the same way it is possible to extract uranium and other elements from seawater if we forget economy. These reserves are practically inexhaustible. Elements which we encounter in the *sediments* and in *concretions* originate predominantly from the continents. Only a minor percentage of the material is from submarine volcanism and related hydrothermal activity. Responsible for the formation of mineral deposits are enrichments processes such as selective sedimentation, where mechanical and chemical resistance of the original material, currents, bottom morphology, temperature, and seawater composition play an important role. Biochemical processes with selected concentration of some elements in the skeletons of marine organism may be also of importance.

The formation of *concretions* is very common in the marine environment and represents another enrichment process. Important concretions are those of calcium phosphate which contain uranium and fluorine and ferro-manganese nodules. The latter may become important as a source of raw material. Accumulations of Cu, Ni, Co, Ti, V, and Pb also occur in the ferro-manganese nodules. The content of manganese in the nodules is between 8 and 40%, that of copper and nickel up to 1.5%. Ferro-manganese nodules rich in copper and nickel occur, for example, within a 550-mile-wide transpacific belt approximately 600 miles south of Honolulu. At present we must consider the deposits of copper and nickel containing ferro-manganese nodules as "resources" because there is, as yet, no proven technique available for producing such materials from beneath several thousand meters of seawater. They will be exploitable reserves when economic production is possible. The metallurgical problems for dressing the very fine-grained and very complex ores must be solved. The environmental impact on the seawater also should not be forgotten. High investment costs for a general recovering system have to be considered and the legal aspects in relation to sovereignty over the seas cannot be neglected.

On *beaches* and at shallow depth on the continental platform, waves and currents are mechanically sorting sediments in such a manner that resistant and heavier materials accumulate selectively. The concentrated material in marine placers, such as cassiterite, zircon, rutile, ilmenite, monazite (cerium and thorium), and diamonds, has long been produced.

Another factor of uncertainty in resource estimates is: *improvements in mining technology*.

There exists the possibility of discovery and assessment of resources presently untouched by our deepest mines and wells. At present, however, physical limitations upon depths to which mining activities can be carried on impose restrictions not only for the evaluation of hypothetical resources at great depths but also on the chances of their recovery. Development of more adequate, safer, and more efficient mining systems may significantly increase underground extraction in the future. An example of improved mining technology for the future times is the research on *in situ* combustion of oil shales.

Basically *improvements in dressing* (another factor of uncertainty in resource estimates) are dependent not only on technology but also on energy input, economics, and environmental impact. With regard to technology, some metals are frequently lost in the dressing processes and could be recovered by improved technology. One example is vanadium which is lost during operations in treatment of crude oil, another is niobium lost in bauxite dressing, and a third is the uranium which remains in some fertilizers.

New dressing methods, such as biological leaching of various ores of nonferrous metals, may considerably increase the recovery of these elements. The extraction of nickel from ultrabasic rocks such as serpentinite, which contains 0.2–0.4% nickel, depends on improvements in metallurgical technique. In northwest Argentina, for example, is abundant serpentinite (Sierra del Toro Negro, La Rioja), which contains nickel (up to 0.5%) and asbestos (5%). Neither the extraction of asbestos nor of nickel is economical at present. Combined extraction involving air suction to recover asbestos from the broken rocks as well as recovery of nickel could eventually lead to an economic process.

Many other similar processes could be mentioned in which improvements in dressing and metallurgy would cause a considerable increase in the recovery of some metals.

Finally, to paraphrase Brooks and Andrews (1974) the discovery of a new deposit adds a new mine to the stock of a single country, but a new technology can open up resources across the world. Even modest advances in technology result in mineral deposits becoming more rather than less available and in mining in more rather than in fewer regions.

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MINERAL RESOURCES—AN ELUSIVE TARGET OF VARIABLE DIMENSIONS

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INTRODUCTION

Mineral resources constitute the essential material basis of industrial society. The question of how to maintain a continuing flow of mineral raw materials without intolerable environmental or socio-political consequences is a central issue in attempting to formulate a plan of action for bettering the future prospects of mankind.

The factors that determine the quantity of minerals available are complex, both for the world as a whole and for its parts. What is available depends on where you are; on when you are there; on the geological and metallogenic characteristics of the region; on the fiscal and energy costs of mining, mineral processing, transportation, and fabrication. It also depends on environmental and sociopolitical costs such as pollution of air and water, disturbance of the land surface, thermal imbalances, the dislocation of people's lives in a variety of ways, and international tensions. It is no wonder that such a situation leads to a variety of ways of stating the problem, a variety of assessments of its tractability, and a variety of proposed solutions. Indeed, it sometimes seems as if otherwise intelligent and well-informed people were more interested in the semantics of the problem, or in staking out and defending particular positions with respect to it, than in coping with it. I will proceed on the assumption that we would not be here if we did not both see a problem and wish to cope with it. But semantic issues cannot be ignored entirely.

One of the main semantic problems turns on what is meant by the term costs, and by the use of other terms like "infinite" or "near infinite", which arise from observations such as that "the entire planet is made of minerals" and that metals once mined, extracted, and fabricated do not leave the earth but remain available for reuse. When I speak of costs, I speak not only of fiscal costs. I include the total costs of mineral production and use, more of which should be converted to fiscal costs by various ameliorative and restorative actions, but costs society pays, nevertheless, in one way or another. In the long range, one must include in the costs to humanity not only the costs of protecting and restoring its environment, but the international tensions and threats of armed conflict that arise where mineral lifelines are threatened. As for the use of terms like infinite and near infinite as applied to earth and its resources, they simply make no physical sense, even though absolute quantities of any given element may be very large. The arithmetic trap that leads to such unrealistic statements is matched in absurdity only by the problem of where the ever-growing hordes

of undernourished humanity are to stand while the entire crust of the earth is mined beneath their feet!

It is interesting to note that even a good many of those who argue that there are no economic limits to what can be produced in the way of mineral resources agree that other limitations exist (e.g. Brooks and Andrews, 1974). Although they do not include these factors in their cost estimates, they foresee large problems of environmental pollution and economic dislocation arising from continuing high rates of exploitation, especially as ever lower grades of ore are mined to supply growing world demand and old, populated mining regions are closed out. The conclusion ordinarily reached is that the growth of such adverse effects will lead eventually to limitation of population growth, consumption and production; that this will lead to new "natural" balance; and that such a world in balance will live on recycled metals and substitute materials. That is certainly not an impossible dream, although to depend on its working out without great intervening hardships for mankind calls for a very high degree of optimism. Indeed, there are those, including myself, who believe that mankind should seek less hazardous ways of achieving the new balance that nearly all knowledgeable people agree must eventually come.

Nevertheless, if we really knew, even within an order of magnitude, what the ultimate "safe" production of mineral resources was likely to be for the world as a whole, for individual nations, and for specific commodities, we would be in a better position to deal with other aspects of the predicament of mankind.

The problems of arriving at such estimates are not negligible. The target moves, and its dimensions vary, as social preferences and opportunities change, as technology and its economic feedbacks change, as geography changes, and as geological knowledge and concepts change.

The rest of my discussion will deal primarily with metallogenic and geographic variations, and with physical limitations as they affect the precision and accuracy of mineral resource estimates.

ESTIMATING RESERVES, RESOURCES, AND TOTAL STOCK

In the simplest terms, mineral raw materials useful to man comprise three categories: (1) the *total stock* within the earth; (2) that part of the total stock which might under conceivable circumstances be obtained at a cost in all terms that would make it profitable and sensible to do so, and which may therefore be considered as a potential *resource*; and (3) that part of the potential resource which has become a *reserve* by virtue of being physically demonstrated to exist in economically obtainable form.

In estimating *total stocks* we could, of course, consider the entire earth. In addition to other problems, however, the core and mantle of the earth are not likely to become accessible to mineral prospecting and development on a large scale, so we may limit our considerations to earth's outer 10 to 35 kilometers—its "crust". The composition of many crustal rocks is known from chemical analyses, and, from these, we arrive at estimates of "average crustal abundance". The product of average crustal abundance for a given element multiplied by 2.4×10^{19}, the mass of the crust in metric tons (under sea and land alike) gives the total stock for that element, perhaps within an order of magnitude. The numbers obtained are, of course, very large.

Estimates of *reserves* also are relatively simple to make. One just gets the figures from all mining enterprises and adds them up. If each estimator gets the same numbers and adds

them correctly, the precision is good, but the meaning of the numbers is clouded with ambiguities involving price, cutoff grades, and legal complications and development policies that influence how large a reserve it is practicable to develop and announce for a given mine or district. In any case, world reserves of the elements are not known with a very high degree of accuracy. They are mainly useful in estimating lifetimes of supplies of a given mineral or element *known* to be available at a given rate of demand. Such lifetimes, however, can be very misleading. When they are obtained by projecting current rates of demand, the usual pattern, they give unrealistically long lifetimes for the quantities considered. When growing rates of use are taken into consideration, they may give excessively short lifetimes by failing to consider extension of reserves by economic factors or geologic discovery, or by substitutions of materials or technologies leading to reduced rates of demand growth.

What we should really like to know is: what are the *ultimate recoverable resources*, taking all kinds of costs into consideration, and where are they located? It seems evident, as Dr. V. E. McKelvey has observed on several occasions, that there must be some relation between ultimate recoverable resources and crustal abundance, or total stock. But what is the relation? As you heard a short while ago, McKelvey (in U.S.G.S. Prof. Paper 820, Brobst and Pratt, editors, 1973, and elsewhere) has also introduced the idea of *conditional resources* and *undiscovered resources* (both *hypothetical* and *speculative*) as an aid to the discussion of the relation between ultimate resources and total stock.

Unfortunately, no simple way is known for achieving sensible, direct estimates of ultimate reserves. In addition to their relation to the various kinds of cost factors, such estimates, for a given area, depend on whether a particular element is present or not, in what concentrations, how dispersed, and in rocks of what type and age.

The latter factors, unfortunately, are not sufficiently considered in estimates ordinarily published. A favorite rule-of-thumb among mineral economists is that the quantity of the substance sought increases with decreasing grade—the so-called grade-tonnage, arithmetic-geometric, or Lasky ratio (Lasky, 1950). Although this appears to be roughly true for some kinds of ores, in some places, down to certain grades, it does not apply to others; and it does not apply generally even to the porphyry copper deposits (Singer, Cox, and Drew, 1974) from which the idea was initially formulated.

A great difficulty is that there are many different kinds of mineral deposits and no single rule applies to all. We can, however, make some sweeping simplifications that are doubtless invalid in detail, but which may illuminate the problem. Mineral deposits in general are formed either by endogenetic or exogenetic processes. *Endogenetic processes* are those that take place within earth's crust as a result of igneous and metamorphic events. Their effect is usually concentrative. They enrich local segments of the crust far above average crustal abundances for particular minerals or elements. *Exogenetic processes* are those that take place at or near the surface of the earth as a result of weathering and the movement of meteoric waters. They may be distributive or concentrative. They may disperse gold from a primary ore but concentrate it in placers. They may create exogenetic ore deposits like bauxite or enrich older exogenetic or endogenetic ore bodies by selective removal of other elements. While enriching some ore bodies they may eventually disperse others entirely.

In general it seems that exogenetic ore deposits and potential resources are more likely than are endogenetic ones to array themselves along a single, relatively symmetrical, logistic distribution curve, that is to obey (approximately) the Lasky ratio. Endogenetic ores are more likely to show a bimodal type of distribution. One class, probably comprising

most known endogenetic ore deposits and similar undiscovered ones, seems to cluster around one smaller distribution mode that is far above average crustal abundance. A substantial gap probably exists between such concentrations and the main logistical curve of crustal abundances for the same element.

Such factors complicate our attempts to estimate ultimate mineral resources, whatever economic, sociopolitical, and demographic model we choose to cast them in. The preferred habits of minerals of different type show large variations in the nature of their host rocks, in age, and in space.

GEOGRAPHIC VARIATION

It is, of course, well known that abundance of the elements and the minerals that contain them vary greatly with location. A mining district is a place where certain types of metals or minerals that are not intrinsically unusual either greatly exceed their crustal abundance, or are easily concentrated because of some distinctive physical property such as specific gravity, magnetism, or chemical reactivity.

We need not linger on this subject. The unevenness in world distribution of minerals is front-page news. We all know about the concentration of oil in the Middle East, of oil shales in the U.S. and Brazil, of tar sands in Alberta, of diamonds in South Africa and Yakutia, of tin in Bolivia and Indonesia, of mercury in Spain and Yugoslavia, of molybdenum in a small area of the Rocky Mountains, of porphyry coppers and massive sulfide deposits in certain mountain ranges along continental margins, of gold in a few of the more ancient areas of the world, and of the almost total dependence of Japan's great industrial development on imported raw materials.

A more interesting question is *why* mineral deposits are unevenly distributed over the earth and how we can better aim for the elusive, moving, and variable targets they present.

METALLOGENIC PROVINCES AND EPISODES

One way of improving our ability to identify target areas is to analyse scientifically the kinds of geological and geochemical processes that are involved in the formation and localization of ore deposits. Such analyses have led to the recognition of a strong preference among many types of mineral deposits for rocks of specific kinds and ages, in specific parts of the earth. Mineral deposits show a correlation with the age, structure, and geochemical nature of the enclosing rocks.

Thus we come to the recognition of metallogenic provinces and metallogenic epochs, which, in turn, has led to a still small, but important, global program for the preparation of metallogenic maps of the earth under auspices of the International Union of Geology and Geophysics and the leadership of Prof. Pierre Laffitte. More recently, the sweeping concepts of plate tectonics have brought sense to some of these localizations, especially to those seen along the leading edges of continental plates in convergent and overriding juncture with the downgoing edges of ocean plates, or in areas of formerly convergent continental plates. A number of observers have pointed out that this is where a large proportion, if not all, of the known porphyry copper deposits of the world are located. Furthermore, there is a strong tendency for such deposits to be found in rocks between about 30 and 120 million years old, with a concentration in rocks around 60 to 70 million years old. Precious metals

of late Mesozoic to Tertiary age, tin, and a number of other metals are found in similar settings.

The largest and richest gold deposits of the world, however, are found in the ancient sandstones of the Witwatersrand and in still more ancient greenstone belts within the continental nuclei. They were formed by endogenetic processes, acting within a particular geochemical milieu, over a span of time reaching backward from about 2.6×10^9 years ago, when the crust of the earth was thinner than now and the geothermal gradient steeper, then locally redeposited.

The formation of bauxite and related lateritic mineral deposits is a function of chemical weathering related to particular times and parts of the earth—most notably to the tropical and subtropical regions of the globe during relatively warm and equable climates such as prevailed widely in late Cretaceous and early Tertiary time. Of course, rock types initially rich in alumina are favored—high alumina clays, syenite, and anorthosite, for instance. Such rocks, indeed, are themselves locally used as a source of aluminum and will become increasingly important as ores as the bauxite is depleted.

Another example of metallogenic provinces and episodes is provided by the famous banded iron formations which supply the great bulk of the world's iron. Several important episodes of banded iron formation are recognizable, all having been completed before about 2×10^9 years ago. The most important, the one during which all of the great iron deposits whose reserves or probable reserves are measurable in terms of tens of billions of tons, took place between perhaps 2.2 and 2×10^9 years ago. The major deposits appear to be exogenetic ores that precipitated chemically from the open waters of marine basins, on subsiding shelves along the continental margins of the time, and were at places exogenetically enriched by later oxidative weathering. The processes involved were so effective and so extensive that iron is one metal for which shortages are not likely to develop in a rational world. There has never been another episode of iron formation of such magnitude, probably because the one described was the result of unique early earth conditions of hydrosphere and biosphere that have not been repeated on a large scale.

Whether or not one believes that really common rock will ever be mined as a source of many raw materials, it will always be sensible, in man's retreat to ever lower grades of ore, to seek the higher grades first and to base his technology, in so far as possible, on the more abundant minerals.

In attempting to do this we will need all the help we can get from the concepts of metallogenic provinces, of metallogenic episodes, and of plate tectonics. Efforts in these areas should be supplemented by and integrated with active global and regional programs of geologic mapping and research, geochemical census, technological research aimed at improved mining and extractive practices, and constant effort to eliminate or minimize adverse environmental effects—all considered as proper parts of the costs of maintaining healthy industrial societies. One goal of technology should be to assess what kinds of industrial society could be maintained on common and abundant mineral commodities alone—on iron, aluminum, magnesium from the sea, and the silicates; commodities whose extraction in very large quantities need not have unmanageable environmental or sociopolitical problems.

SOME PHYSICAL LIMITS TO ULTIMATE MINERAL PRODUCTION

Thus we see that the quantities of metals and other materials in the earth's crust or

dissolved in sea water are very large, even though not infinite or near infinite in any physically meaningful definition of those terms. We also see that there are ways of assessing scientifically the mineral prospects of various parts of the earth and of narrowing the target areas to places where the higher grades of yet undiscovered and unexploited ores are to be found. Does this mean that we can mine and recycle the entire crust of the earth or recover the 10 billion tons of gold that are dissolved in ocean waters? It does not—although fortunes may be made and lost in the effort to do so. I have gone through the exercise for copper, to try to come up with some reasonable number for the amount that might eventually be mined. Multiplying the mass of the crust by the average abundance of copper (55 parts per million) gives a total stock of about 1.3×10^{15} metric tons. We will never mine that much copper. No one knows the real figure for the tonnage of copper that eventually will be mined, but it must be several orders of magnitude smaller than the total stock. My own rough estimates suggest that somewhere between 10^9 and 10^{10} tons is possible for copper. This is between 4 and 30 times presently known reserves. A ten-fold increase, at current rates of growth of consumption, would lead to depletion around the year 2050. Obviously we will not mine copper at constant rates of increase right up to the point of 3.4×10^9 tons and then stop. Many factors can and some will intervene to prevent this happening. But, as Professor Marois has advised in his presentation of the conference, mankind should be in "a state of permanent watchfulness" as regards the flow of copper and other raw materials deemed essential to an efficient functioning of society.

In maintaining such a state of watchfulness we should be aware of some physical limitations:

1. The entropy of close systems always increases. With respect to minerals, Earth is a closed system. Free energy is converted to bound energy and concentrated materials become dispersed. We restore such concentrations at a cost in free energy which is forever lost to the growing stock of bound and thus unavailable energy.

2. Even though the potential quantities of free energy are very large, their use involves hazards to ecosphere and biosphere that increase as the quantities of energy used increase.

3. Exponential growth of demand, being brought about and to be brought about by exponentially growing world populations, increasing per capita consumption on the part of the now affluent, and the expected and greatly to be desired increases of supply to the now deprived peoples of the earth creates an almost insuperable problem. No rate of production can meet such requirements for long, even were it feasible, without very serious and probably intolerable environmental consequences and growing global tensions.

4. Half-way measures such as recycling are simply that—half-way measures at best where demand grows exponentially—which is not to argue that recycling should not be emphasized and improved. Bear in mind, however, that even total recycling, were it practicable, would get only half of what is needed for each doubling of demand. Even substitution, helpful though it is, and can be, rarely eliminates continued growth in demand for the commodities substituted for where the whole economy is growing. Curves of growth in the use of glass and paper for containers, for instance, do not even show an inflection at the point where plastic was introduced.

5. Even human ingenuity, vain and self-congratulatory though we may be in proclaiming it the one truly illimitable resource, does have limitations. We cannot go faster than the speed of light, extract nickel from the core of the earth, abolish entropy, or circumvent other laws of physics. Technology, for all its past and expected future triumphs, must even-

ılly reach a plateau. Indeed, we may already be approaching such a plateau, especially if ɔport for the essential underpinning basic research continues to decline.

One of the nobler aspects of human nature is our drive to probe the limits, to thrust ward until we can go no further and then perhaps to gain still a bit more ground by ne masterful feat of ingenuity, circumvention, or sheer determination. This does, indeed, m to be a valid and stimulating outlook for the exploration of space or particle physics. is quite a different and more doubtful matter whether such a course is a wise one for ınkind in his occupancy and use of planet earth. Our exponentially filling world and ɔwing material consumption may simply involve quantities now too large, combined th rates of growth now too fast, to bring under control *after* impending limits come arly into view.

Growth in itself has long been seen as a goal by industrial societies. Indeed, great ad- nces for mankind in general—in sanitation, medical care, and education, for instance— ve gone hand in hand with industrial growth.

But the genie is out of the bottle. What was or seemed to be good for parts of the world er a particular interval of history leads increasingly to adverse environmental and socio- litical effects that call for a reexamination of goals and means.

Surely growth as a *goal* makes no sense after maturity has been attained. Even in reaching ıturity, growth is only a means to an end and not a sensible end in itself.

The peoples and nations of the earth need to analyse and define their goals in fundamental manistic terms. Having done this, it will be appropriate to ask whether material growth ı good means to agreed-upon ends—and, if so, to what ends and at what rates? Combined th this should be a thoughtful evaluation of other means to sought-for ends. If, after the ablishment of a floor of basic physical comforts, it is a goal of societies to enhance the man condition, it is not difficult to think of non-materialistic means toward this end. will be difficult, however, to establish even that essential floor of minimal basic ysical comforts and adequate nutrition for the world at large if global population growth ntinues.

That state of permanent watchfulness so wisely advocated by Professor Marois, and so eatly to be desired, needs to be global, many faceted, and unwavering. And this watch- lness needs to be implemented by national actions and global convenants aimed toward uity among men and nations and the general improvement of mankind, not only for ing but for future generations. An essential step in bettering the outlook for the future is initiate, with all possible speed, such policies and actions as are best calculated to bring ɔrld population to a state of balance with the capabilities of the planet to sustain it in- finitely at a reasonable level of comfort for all.

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DISCUSSION

BERMAN: La plupart des calculs que nous avons entendus, ou qui ont été réalisés, sur les estimations des ressources minières, supposent la possibilité d'exploiter, mais surtout de trouver des filons qui, selon les auteurs, sont situés à 400 m, 1 200 m, ou même jusqu'à 15 km de profondeur. Cependant, même lorsque l'on a localisé des zones où la probabilité de trouver des dépôts est la plus forte, il faut encore trouver ces dépôts, si bien cachés soient-ils. Or actuellement presque toutes les mines découvertes sont fondées sur des indices qui existaient en surface. Je voudrais donc savoir si les techniques actuelles pour trouver des gisements dont aucun indice n'existerait en surface sont suffisantes; et si tel n'est pas le cas, si les recherches en cours dans le monde pour trouver de telles techniques sont suffisantes.

CLOUD: No, I don't think present techniques are adequate and not enough research is being done. Concerning the effort to develop techniques, geophysical, geochemical prospecting and otherwise, for discovering concealed ore deposits—although there are small programs in this direction within U.S. Geological Survey and other places, that effort needs to be greatly enhanced and supplemented. I would refer that question to Dr. McKelvey, who is obviously much more familiar with the U.S.G.S. program than I.

McKELVEY: There have been some discoveries already of some deposits that are wholly concealed, but I concur with Dr. Cloud that that topic of developing better methodology for the identification of concealed deposits is one that, while it is being pursued, in my estimation is not being pursued at an adequate level.

CLOUD: I might add that in addition to developing the techniques for searching for concealed ore deposits, there is a great need for investigation also in the methods for recovering any deposits found from very great depths.

INVESTISSEMENTS NÉCESSAIRES POUR LA PRODUCTION DE NOUVELLES RESSOURCES DANS LES ÉCONOMIES DES PAYS INDUSTRIALISÉS

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Evoquer la disponibilité de ressources minérales dans le futur, en regard du phénomène de la croissance économique, c'est s'interroger sur deux questions essentielles:

— l'accroissement des échanges entre les différentes régions du monde, échanges où les matières premières jouent un rôle primordial, puisque c'est à partir d'elles que vont s'opérer les activités de transformation,

— l'effort financier et industriel engagé dès le présent, c'est à dire l'investissement, propre à assurer dans une ou deux générations une capacité de production en rapport avec l'évolution de la demande.

Je me limiterai ici à traiter des investissements nécessaires au renouvellement des ressources dans les économies des pays industrialisés. Pourquoi cette distinction?

A la lueur d'évènements récents, qui ont affecté non seulement les substances énergétiques, mais encore un bon nombre de matières minérales—phosphates, cuivre, mercure, bauxite, minerais de fer, etc.—une tendance s'est fait jour dans l'opinion publique, qui viendrait à considérer le problème de l'exploitation et du renouvellement des matières premières en terme d'antagonisme entre pays insuffisamment développés et en même temps détenteurs de l'essentiel des ressources pour l'avenir, et pays riches et industrialisés s'efforçant de puiser chez les premiers—et à leur détriment—ces ressources dont ils ont un besoin impératif.

Cette analyse quelque peu sommaire ne résiste pas à un examen objectif de la répartition des productions minérales et des ressources potentielles dans les différentes régions du monde. Néanmoins, il apparaît qu'à des degrés divers, la plupart des nations industrialisées, —quelle que soit l'importance de leurs productions et de leurs ressources nationales, ont besoin de compléter leurs approvisionnements auprès de pays moins développés, et qu'à l'inverse ceux-ci auront encore besoin, tout en organisant progressivement leurs propres industries de transformation, de continuer à vendre une fraction notable de leurs produits minéraux.

De cette situation d'ensemble, il ressort que les économies des pays industrialisés, tout en ayant à soutenir un courant d'investissements dans les pays en voie de développement—sous forme d'aide ou de participation directe, préservant les droits de ceux-ci sur la propriété des gisements et la commercialisation des produits—ont, sur leur propre territoire, un rôle à jouer dans l'effort de renouvellement des réserves disponibles, au moins équivalent à celui qui devra s'opérer dans les territoires plus neufs.

Nous devons donc nous poser les questions de savoir dans quelles conditions, dans quelles directions et à quels coûts devront s'exercer les efforts entrepris pour augmenter les réserves.

LES CONDITIONS

On peut dégager trois motivations essentielles aux investissements dans le secteur des matières premières.

L'importance des besoins futurs impose de chercher partout à valoriser les richesses naturelles, sur tous les continents, et même dans les zones immergées des océans. Les chiffres de croissance de la consommation de l'acier, des métaux non-ferreux et d'autres matériaux de base d'origine minérale, qu'on peut tirer par exemple de la lecture de rapport de juin 1973 de la Commission Nationale des Etats-Unis sur la politique des matériaux, sont bien connus, sans qu'il soit nécessaire que je les énumère ici.

Les statistiques françaises appliquées à la décennie écoulée indiquent que le taux moyen de progression de la consommation annuelle a été particulièrement fort pour certains métaux ou certaines substances: 6,5% pour l'aluminium, 7% pour le nickel (ce qui correspondrait à un doublement de la consommation tous les dix ans, si un tel taux devait se maintenir) et 9% pour la fluorine.

La nécessité du développement économique impose aux pays dont le revenu per capita est encore très insuffisant de valoriser leurs ressources, afin de dégager les revenus qui leur permettront de prendre part au progrès général autrement que par le biais d'une assistance internationale d'une durée illimitée et contraignante.

Le réflexe légitime des pays industrialisés de préserver une autonomie au moins relative de leurs approvisionnements, leur impose un effort de prospection et de mise en valeur de leur propre territoire.

"Un plan d'actions pour l'humanité", thème central de nos débats, implique que ces nécessités se résolvent non dans des voies conflictuelles, mais en terme de complémentarité.

LES DIRECTIONS

Trois grands champs d'action sont ouverts aux investissements de la recherche minière:

Dans les pays industrialisés, où les gisements affleurants ont en général été reconnus, les prospections devronts 'orienter vers des gisements d'accès plus difficiles, c'est à dire qu'elles imposeront l'élaboration et la mise en oeuvre d'une technologie de plus en plus complexe.

Considérons à cet égard le montant total des investissements consacrés en 1972 aux recherches minières sur le territoire français (y compris pour le nickel de Nouvelle-Calédonie, mais en laissant à part les prospections pour l'uranium, comptabilisé avec les substances énergétiques): ce montant s'élevait à 118 millions de francs, auxquels il convient d'ajouter 14 millions de francs affectés à la méthodologie de la prospection et aux études de valorisation des minerais, soit donc un total de 132 MF. Les dépenses ainsi engagées représentaient près de 6% de la valeur de la production minière de l'année précédente, valeur qui se chiffrait à un peu plus de 2200 millions de francs. Il est significatif de comparer le rapport calculé pour la France à celui établi pour le Canada, qui, pour des investissements de l'ordre de 95 millions de dollars,* donne une valeur sensiblement inférieure, d'environ 3,5%. L'explication de cette différence peut être donnée dans le fait que de vastes étendues recèlent encore au Canada bon nombre de gisements de type classique. Dans une certaine

mesure, et en dépit des intenses efforts d'exploration menés ces dernières années, les conditions de la prospection s'apparentent ici à celles rencontrées dans des pays moins développés.

Les pays en voie de développement, qui constituent un deuxième vaste champ d'action, bénéficieront grâce à leurs ressources potentielles encore intactes, d'un certain délai pour s'adapter aux technologies les plus sophistiquées de la recherche minière. Il leur faudra néanmoins les maîtriser quand, à leur tour, ils auront besoin de se tourner vers des ressources plus difficiles à mettre à jour et à valoriser.

La mise en valeur, en troisième lieu, des ressources cachées des océans se place à l'évidence en avant-garde du progrès technologique. L'objectif essentiel est de rendre compétitive avec les sources traditionnelles d'approvisionnement, l'exploitation de métaux parmi lesquels le manganèse, le cuivre, le cobalt, le nickel, etc., qui sont contenus dans des couches de nodul estapissant les grands fonds océaniques, et pour lesquels des chiffres impressionnants de réserves (plusieurs milliards de tonnes) ont été avancés. En l'état actuel, la mise en ligne des procédés technologiques et des investissements requis ne peut être le fait que des plus grandes Puissances industrielles. Néanmoins, la question se pose d'ores et déjà de préserver les droits futurs de tous les pays sur ces ressources, même de ceux qui ne peuvent aujourd'hui prétendre apporter à cette entreprise une contribution technique ou financière. La troisième session de la conférence sur le droit de la mer, qui vient de se réunir à Caracas de juin à août 1974, s'est efforcée d'avancer des solutions juridiques à ce problème.

LES COÛTS

J'en viens à présent à l'évaluation des coûts représentés par la mise en oeuvre de nouvelles unités de production. Dans un rapport de décembre 1973 sur l'Industrie minérale, la Banque Internationale pour la Reconstruction et le Développement indique le montant en 1971–1972 des investissements miniers: 7 milliards de dollars par an pour l'ensemble des pays en économie libérale. Ce montant inclut, en sus de la recherche minière, la création de nouvelles mines ou l'extension de complexes déjà existants, qui comprennent outre la mine et son infrastructure, les installations de traitement des minerais jusqu'au stade de la première fusion pour les métaux. D'après ce même rapport, plus de 70% de ces investissements auraient encore lieu actuellement dans les pays de développement avancé. La Banque estime en outre que le montant des investissements pourrait doubler d'ici le début des années 80, la part des installations réalisées dans les pays en voie de développement augmentant progressivement jusqu'à représenter environ 40%.

Ces chiffres nous incitent à quelques réflexions. En effet, le taux de croissance attendu pour les investissements dans la recherche, l'exploitation et le traitement des minerais devrait à peine couvrir l'augmentation de la demande en métaux et matériaux de base si cette augmentation se maintient au rythme suivi les quinze dernières années. Cette affirmation repose sur le fait que le coût unitaire de production† (extraction et raffinage) tend à s'élever par suite de la difficulté croissante de découvertes et d'accès des nouveaux gisements, de l'abaissement des teneurs d'exploitation et de l'augmentation du prix de l'énergie in-

* Chiffre 1970.

† Evaluation du montant de l'investissement par tonne annuelle produite (rapport BIRD fin 73, avant effets de l'augmentation du coût de l'énergie): bauxite: 25\$; alumine: 200 à 250\$; cuivre électrolytique: 2500 à 3500\$: aluminium: 800 à 1200\$; nickel (mine et fonderie): 8000 à 15 000\$, suivant le type de minerai traité.

corporée au traitement des minerais. En outre, les investissements réclamés par l: production de nouvelles unités sont de plus en plus importants avec l'accroissem taille de ces dernières: une liste récente de projets miniers parvenus à un stade a réalisation dans différents pays développés montrait que plus du quart de ce nécessitait des investissements supérieurs à 100 millions de dollars, cette fraction ı tant ainsi à elle seule 70% du total des sommes à investir. Pour certaines de ces unités, l'ampleur de l'investissement atteignait 400 millions de dollars,* ce qui r une somme considérable, même pour des Compagnies minières parmi les plus imp

Face à cette augmentation de la taille des objectifs, les risques et les difficultés i à l'aventure industrielle que constitue un projet minier vont agir comme un frein] il n'est pas rare en effet que les dépenses annuelles de la seule recherche minière a ou dépasseh+20% du cash flow de l'entreprise, c'est-à-dire de sa force vive qui lui p parer aux amortissements des équipements déjà opérationnels, de renouveler sa s par des investissements productifs, de doter ses réserves financières et d'assur actionnaires une rémunération de nature à lui conserver leur soutien.

Dans son évolution actuelle, l'Industrie minière qui tirait traditionnellement sources de son propre autofinancement et des mouvements opérés sur les marchés (taux, se voit contrainte chaque jour davantage à faire appel à des sources extéri financement: secteur bancaire et aide gouvernementale, qui interviendront courai hauteur de 50%—et parfois jusqu'à 80%—du montant des projets.

L'abaissement du taux de rentabilité des entreprises minières s'est ajouté ces (années aux facteurs qui tendaient déjà à rendre plus difficiles les investissements secteur des matières premières. Une récente étude de Evan Just, éminent profe l'université de Stanford, analyse la dégradation, quant au taux de rentabilité dı investi, de la position des mines de fer et des industries primaires des métaux non Après avoir occupé une position enviée dans les débuts des années soixante, ces ir se situeraient désormais au bas de l'échelle (avec un taux de rentabilité moyen de l' 12%) si on les compare à quatorze branches d'activité manufacturière dont les profit se rangent autour de 20%. Il n'est pas sûr que les hausses importantes interv 1973 sur les prix des matières premières, et qui étaient dues à des causes davantag ques et monétaires qu'économiques, inversent fondamentalement cette tendance.

Taille grandissante des investissements, capacité insuffisante d'autofinancement, ment du taux de rentabilité, autant de causes sur lesquelles s'appuient les prévisi pessimistes, qui prédisent d'ici une vingtaine d'années une capacité mondiale de prc des minerais et métaux de base très inférieure aux besoins des industries de transfor Dès lors ces dernières seraient acculées à ne plus satisfaire la demande croissant population mondiale en forte augmentation.

L'apparition d'une pénurie généralisée—due non à des causes naturelles, mai absence de sagesse dans la gestion des ressources qui nous sont offertes—viendr: renforcer le désordre qui tend à s'instaurer dans les moyens d'échange et de p: accentuer l'instabilité des cours par des mesures non coordonnées de stockage substitution, et transformerait définitivement les matières premières en armes de] politique.

Perspective redoutable à laquelle nous ne saurions nous arrêter dans cette ences

* Ordre de grandeur pour l'équipement d'un gisement type "Porphyry copper" devant produir tonnes de cuivre raffiné par an.

nombreuses solutions se présentent pour rétablir les équilibres, solutions qu'il n'est pas de mon propos de développer ici, mais qui vont de l'intervention constructive et modératrice des Puissances publiques aux transferts raisonnables et organisés des Capitaux disponibles, du renforcement des accords bilatéraux à l'élaboration de nouveaux accords internationaux par produit, et enfin à la mise en commun des moyens existants dans des pays de niveaux ou de systèmes économiques différents.

Là se trouvent les voies d'un avenir où les matières premières resteraient ce qu'elles n'auraient jamais dû cesser d'être: un objet d'échange et d'activités pacifiques entre les hommes.

SUMMARY

From an international point of view, the exploitation and the renewal of raw materials seem to give rise to an antagonism between developing countries, in possession of the most resources and rich industrialized countries with few resources. The political oppositions must be overstepped to perceive the mutual dependence of these countries and reveal the necessity of a common action.

The only way for the production to cover the rising demand of an increasing world population is to develop the world resources and consequently to increase investments. The development of the resources is necessary for the poor countries to acquire independence and for the industrialized countries to preserve their autonomy.

Thanks to their advanced technology, the great industrial nations must direct their efforts towards prospecting of difficult deposits, and deep-sea resources exploration and exploitation, while they have to respect the rights of the developing countries to their own resources. So, the industrialized countries must increase the investments in the developing countries, but also in their own territories. The importance of investments, the inadequacy of self-financing and the falling of the rentability rate oblige the mining industry to appeal to other financing means (state and banks).

The elaboration of an international common policy about raw-materials supplies is indispensable to balance the exchange of raw materials.

IMPACT OF HEURISTIC AND PROSPECTING TECHNIQUES ON MINERAL RESOURCES AVAILABILITY AND DEPLETION

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An exploration geologist is responsive to the desire in all human beings to be optimistic concerning overall human development; this is especially true of his professional attitudes. This optimism is reinforced by the recent geologic advances. Looking only at the data for known available materials, regardless of the commodity, the present figures of demand or consumption or any other way of comparison are generally several times larger than the figures, let us say, several decades ago. Apparently the world-society is well on its way in establishing a stable growth in mineral commodities, with only small disturbances such as might be caused by human behaviour but which affect only to a small extent the actual advances in natural resource development.

This optimistic view is disturbed, however, when the non-renewable nature of mineral resources is taken into account. Each used resource unit is completely or nearly completely exhausted—not taking recycling into consideration—and the natural processes do not replace the consumed resource at anywhere near the rate of today's exploitation. In this process we participate as experts concerned with only meeting the threat to mankind of a consumption famine. We are in general not at all involved with the problem of how to guarantee the supply of necessary natural commodities to the world for the long run. Today it seems apparent that most are concerned with the problems of price and technology and not with the anxiety concerning the long-term availability of world resources. In a similar way, geologists are extending their prospecting to the ocean floor, to remotely accessible areas, and to increasing the by-products of minor metals occurring in presently mined mineral deposits, not because of the problems now associated with the possible future shortage of raw materials, but because of their technical short-term economic interest.

The present governing bodies in the world societies, except some of the most developed countries, have the policy to find and put into production as much as possible of the known

associated with the magmatic rocks, but which are still deposited as the result of the magmatic activity, exhibit just the overall enrichment in the area in which their deposits are sited. On the other hand, the guides mentioned above for individual deposits are also significant for the zones of ore deposition, and the facts relating to each characteristic are of the same value; however, on another scale, as has been indicated.

With all those data on hand, it is actually possible to detect the deposits whether they are hidden, or covered up to a depth of several tenths of metres, and in exceptional cases up to a depth of several hundred metres. In the case of specific elements with special behaviour, various auxiliary techniques may be applied using those natural characteristics such as radioactive measurements, geophysical and physical measurements, studying the behaviour under different environments, etc., which all enable one to narrow the location of ore deposition. Many such techniques largely depend on the environmental conditions and are confined just to a certain element or elements under determined conditions. Others have a large range of application and may be used under various conditions. In any case, only a few prospecting techniques have large areas of application, among which may be classified mostly the "classical" methods of geological prospection. On the other side, specific techniques of study of physical environments relating to depositional processes, such as temperature, pressure measurements by inclusions, paragenetical associations, use of isotopes for age and depositional conditions, composition of ore fluids by chemical equilibria studies or by the composition of inclusions, microscopy with various techniques, etc., enable a better understanding of the conditions of formation and localization of the ore. The field of prospection in this respect becomes very wide, and consequently specialists of several fields are necessary to assure the correct results concerning the conditions of formation of a deposit. Present knowledge is still limited, as has been indicated by the recent discoveries of various types of deposits which were not recognized previously. Here may be mentioned stratiform deposits of tungsten and tungsten–antimony–mercury formations, rare metals-bearing metasomatites without any association with igneous activity, apogranites with the corresponding mineralizations, etc.

In addition to such normal investigations where surveying techniques are more or less developed, determination of a mineralized zone potential is still a field where professional knowledge is far from complete, and many discoveries in the near past were more due to the prospecting luck than to the strategic and specific investigations. However, it should be admitted that several regions of outstanding potential have been revealed by the proper, well-measured prospecting techniques. Therefore, today interrelated achievements are typical of the domain of applied geology. Under certain circumstances it is feasible to forecast the possibility of a discovery or the potential of an area, whether dealing on the planetary scale or just treating a selected zone. Here, as is normally the case, a divergence of opinions still exists regarding the basic principles and rules to be followed, but some basic facts have been generally accepted. An element may occur only in well-defined geological environments resulting from the evolutionary process of an area, such as part of a geosyncline, the margin of a plate, or a rift zone. Although strong links exist between such parts of the earth evolved in a certain way and ore deposition, it is impossible to forecast whether the ore deposition really took place in such an area. The link among lithology, structure, igneous activity, and mineralization is one-sided, and if all basic conditions for its generation are not fulfilled, no ore deposition should be expected. If knowledge of this space element is supplemented by knowledge of the time of ore generation, then it can be specified what mineral resources may be expected in a given area and, by additional knowledge, also the

chances of a possible discovery. With additional knowledge, understanding can be developed regarding the association of an element with the source rock, whether of igneous or sedimentary origin or even in some cases of metamorphic formation, which associations might be strong, weak, or missing; regional and local geochemical features; regional and/or local geophysical indications, etc. This additional knowledge naturally includes older accepted concepts such as regional and local zoning of ore deposits and zoning within deposits, tectonic deformation affecting ore deposits, association with certain petrographic members of igneous sequences, dissemination into certain sedimentary rock, and physical characteristics of the host rock. Facts are still being collected regarding hypotheses relating evolutionary stages of the earth's crust with metallization; however, much progress has been made in better understanding why ore has been generated and deposited at certain places. This knowledge is still incomplete as might be exemplified by the discovery of coppers bearing carbonatites. On the other hand, if the concept of origin of the mineral deposits is disputed, it is difficult to estimate the potential of an area. For example, the long-lasting dispute between plutonists and neptunists is still active without any withdrawal by either side, and moreover, no efforts have been made to bring together the facts and observations, which are in any case the same, but can be interpreted differently. A typical example in this respect is strata-bound deposit, where on the same ground conclusions concerning origin are completely opposite. Even more speculations are involved concerning the origin of the elements, as the conclusions are mostly backed by trace-element analyses of ore and ore minerals, isotopic composition, and the position of deposits. For example, mercury has been related by traces of platinoids in several deposits in the world to the generation of ultrabasic magmatic rocks and transformation from very young deposits to older formations. However, other data support an origin connected with either acid or basic magmatic activity in deposits of varying age. Such divergent concepts and facts indicate the actual state of knowledge of ore genesis which is used as the basis of appraising the mineral resources of some areas.

The latest fashion in geology is to ascribe to the various deposits a deep-seated source and associating tectonics and ore formation. The new theory of the sea floor spreading and plate tectonics, the geophysical data concerning regional and planetary properties and composition of the various zones of the earth supports this picture, and as a result have assisted in building a more reliable and proper concept of the location of ore deposits, their size, and possible extentions. In the light of the new wave in general geochemical research developed in the last few years, it might be expected that some answers to the basic questions of the ore formation would be clarified, and such knowledge used for the needs of prospecting. Even though the geochemical cycles of the elements during geological history are as yet not sufficiently applicable for immediate use in mineral surveying, they are of a great help in better understanding the habitat of elements. Therefore, it is not surprising that in some parts of the world speculative resources have been estimated. Several obstacles are still present concerning heuristics, its accuracy, and general application, as the main part of the data so far tends to be just locally successful without a general serviceableness, but the little stones of this mozaic are steadily building into a picture.

We are aware that forecasting on the planetary scale and selection of the target areas is still in the beginning stage, although there are known cases where such studies have furnished outstanding results. The Witwatersrand type of mineralized conglomerate has been discovered on the Siberian Platform under thick tundra soil cover by the use of the computerized analysis of all known data and facts from both regions involved. Such results

may be achieved also with the help of dispersed individual discoveries, which may prove to fit a general model of the geological events, as for instance are ecliptic belts of "porphyry copper" deposits including the belt extending from the Balkans to Pakistan and perhaps further, the Caribbean belt from Cuba to Puerto Rico, and the Pacific belt from New Guinea to the Solomon Islands. The embryonic stage of the forecasting is completed as shown by these numerous examples.

The near future development of the natural resources seems to be also insured by mining and technological advances enabling large and low-grade deposits to be economically mined. Such appropriate deposits should be searched for with the available prospection techniques to match the trend of growth in demand for mineral commodities, as has been attained in the past. Satellites may become very important in the future application to discovery of ore deposits, using techniques which have been waiting their application on the earth.

The growing needs for raw materials pose the question how geologists are actually equipped to meet the challenge. The canciform spreading of data concerning applied geology, the different approaches to the same problem due to differing trends in geological education, and the variety of languages in which the treatises are written play a large part in lessening the possible future achievements. In the field of applied geology nearly 50,000 articles are published yearly, and a geologist, dealing just with his specialized working field, has at his disposal at least several thousand papers every year. Presuming that only half of the articles deal with new discoveries, then it is possible to imagine the troubles of the professional who would like to follow the selected geological events closely—not to mention the linguistic difficulties. The language barrier is very obvious. Articles written in those languages have references mainly in the same language, and include in general only a few from other languages, serving as decoration, and sometimes include some translated articles generally selected haphazardly. Therefore, professional isolation, which is not typical for geology only, is a great handicap towards a wide and regular exchange of data and opinions. As certain types of deposits are located in the distinctive environments, and if these are sited in various linguistic areas, then duplicating preliminary research is repeated at every such location, and frequently duplicating research work is also carried out and published. The next hindrance is represented by the conceptual approach to the problem under investigation. The different trends in geology arising out of various approaches of geological education commonly result in the acceptance of the fixed basic framework for the interpretation of facts, but without distinct separation of the observed and measured facts from the interpreted and included data. Thus the "winnowing" of factual information from interpretative data is very difficult and frequently impossible. A typical example of this has been reported recently when a tin deposit which had been formerly described as a replacement fissure filling was classified by another expert from objective field observations only as stratiform or stratabound type. The scientific terms which are used are frequently incomplete and may provoke many misunderstandings, or are used in meanings which do not correspond with the same original sense. The problems originating in this respect may be shown by the massive sulfide deposits, which by the terms and descriptions used are hardly distinguishable from manyo ther types of deposits. Therefore, the use and benefit of the published results are lessened in such cases and are not as valuable as would otherwise be

mineral resources, and on the other hand thwart the expected development. The present knowledge of the prospecting and mineralization process, although well advanced in the last years, is still insufficient for the general evaluation of the mineral resources in the potential zones of the earth's crust and is limited to evaluations to depths less than 100 metres. Reported speculative resources may be several times larger or smaller when calculated by another expert who belongs to a different school or conception than the first. Only reserves, although quite widely treated and estimated in different parts of the world, represent the least variable approximation of our knowledge. Therefore, the estimated potential of an ore-bearing zone, based on the observed facts, is more reliable than the estimate of speculative resources, although even the reserves may be expected to show significant variation. A mineralized planetary belt may be considered and evaluated by the mineralized zones building the belt, and using such an approach would lead to more reliable estimates of its potential. All extrapolations would be backed by certain facts gathered in the field or laboratory, which would be a firm basis for estimating the potential of the zone under consideration for either prospecting or evaluation, however, the prospecting techniques and actual knowledge are still inadequate for making reliable estimates of the mineral resources availability. The estimates which might be presented would give the conceptual approach to the problem involved, although made by the best objectivity and knowledge, shall be considered as reflection of the heuristics presently available.

Today's prospecting techniques applied to the search of mineral deposits are developed sufficiently to ensure in the near future a growth of mineral reserves to meet the increasing needs of humanity; however, the impact of the decreasing availability of the prospective mineralized land will soon introduce a reverse trend, as the speed of discovery in general is lessened, even though more effort is made every day in mineral exploration. We are confronted with a transitional period in respect to mineral resources availability, and for a short period the improved techniques in prospecting, technology, mining, etc., may still keep pace with the growing needs of the world. This is true especially if a better understanding of all processes involved in mineral deposits formation is achieved in order to enable the development of exploration techniques that can successfully locate deeper ore deposits. Deposits extend up to 2 km in vertical direction, and in some cases even more, and if detection techniques would be able to penetrate, let us say, twice as deep as presently, then the mineral availability would be greatly increased. But with the techniques presently applied, using up-to-date knowledge, the exploration depth can be extended only as the exception and not as the rule. As no sudden change in prospecting science can be expected, the mineral resource availability, and corresponding search and detection will remain within the limits imposed by the exploration techniques.

It is up to us to ensure improvement of the heuristic and prospecting, because with joint efforts many problems might be solved in reasonable time and within acceptable financial means. Otherwise, the depletion of presently economic resources of several commodities would soon bring the world societies to develop substitutes, or else they would be obliged to accept a huge increase of costs for their discovery and recovery.

RESOURCES AVAILABILITY AND DEPLETION

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Mineral resources occupy a leading position in the developments of any society. These provide raw materials for building, chemical, electrical, engineering, and heavy industries; inputs for modern agriculture like pesticides and fertilizers; metals, fuels for industrial purposes and transport; and minerals and raw materials for export. They also provide opportunities for employment. Mineral resources, along with other natural resources like forests and agriculture, add in a great measure to the wealth of a nation.

Efficient management and proper utilization of natural resources can transform a mainly agrarian economy into a highly industrialized, technologically advanced and economically independent entity. For example, Australia, Brazil, and Ireland were mainly agrarian economies a couple of decades ago, and belonged to the club of less-developed countries. But today these countries have well-developed mineral industries to boast of, and meet the social needs of their populations. A number of less-developed countries like India and newly emerged independent nations in Africa and Asia have had well-developed mineral industries in the historical past which is evident from the ancient mine workings and slag heaps found in many places.

Prophets have signalled that world mineral supply is dwindling and the world population is increasing with the result that soon we will be running out of mineral resources with dire consequence for mankind. This concept has been based on the extensive consumption of minerals and mineral products in the well-developed countries.

The purpose of this paper is to show that we are not running out of resources. We need to increase the pace of exploration and development activity in the less-developed countries in Asia, Africa, and South America by massive transfer of science and technologies by financing joint ventures.

ROLE OF MINERALS

U.S.A. and the Soviet Union

To produce steel, which is considered a barometer of economic growth, and industrialization of any country, iron ore, coal, and limestone are major raw materials. These raw materials exist within the confines of the U.S.A. and the Soviet Union. The position of economic eminence enjoyed by the U.S.A. and the Soviet Union reflects the efficient development of their mineral resources.

For every ton of steel nearly 5 to 6 tons of

itself shows the magnitude of developments which may have taken place in the United States and the U.S.S.R. in the field of mineral development.

For example, the U.S.A. in 1931 produced 26.36 million tons of steel and 400 million tons of coal. By 1937 the production of steel had been doubled. The steel production in 1971 rose to 110.749 million tons. During the same year 535 million tons of coal was mined and 88.38 million tons of iron ore was produced. In 1931 the U.S.S.R. produced 5.62 million tons of steel and by 1937 had tripled the steel capacity, i.e. 17.73 million tons. The production of steel in 1971 was 120.637 million tons. The coal production during the same year amounted to 591 million tons. The iron ore production in 1971 was 203 million tons.

China

Steel production in China rose from 1.215 million tons of steel in 1949 to 23 million tons of steel in 1972. To produce 23 million tons of steel nearly 50 million tons of iron ore was mined. Similarly, the coal production rose from 53 million tons in 1952 to 390 million tons in 1972. The production of copper, lead, zinc in 1953, respectively, amounted to 8000 tons, 10,000 tons and 10,000 tons. But the production of these metals has stabilized at 100,000 tons per year of each metal. China produced an insignificant quantity of aluminium in 1949, but in 1972, 135,000 tons of aluminium was produced in that country. Eighty-five percent of world reserves of the ferroalloy metal tungsten are found in China. As a result of these developments China has come out of oblivion into a place of prominence.

Japan

Japan was initially importing technology from Europe and the U.S.A. In order to utilize one dollar of imported technology, she provided 8 dollars' worth of national resources. Now a stage has come when they are exporting technologies to those countries. For example, the major improvement they have made is the consumption of coke in the steel making. The coke consumption in 1960 was 660 kg per ton and now it is 440 kg per ton, the lowest rate in the world.

Japan today, which started initially with meagre resources, is challenging to outstrip the Soviet Union and the U.S.A. in the production of steel in the next few years. During the last 25 years by importing large quantities of iron ore and coal from various parts of the globe she has not only become a major steel producer but an economic power to reckon with. The installed capacity of steel in 1972 was 124 million tons per year, which is expected to rise to 148 million tons by 1975. She imported 1.2 million tons in 1950 and about 119 million tons of iron ore in 1972. The steel production in 1972 was 103 million tons. This production is expected to rise between 145 and 155 meter tons/year (*Mining Journal*, June 29, 1973; July 27, 1973).

Australia

Australia became a major producer and exporter of iron ore during the last decade (1960–70). The quantity of iron ore produced in Australia rose from 4.355 million tons in 1960 to 11.53 million tons in 1966 and 61 million tons in 1971. Australia exported only 116 tons of iron ore valued at $A1638 in 1960, whereas in 1967–8, 14.74 million tons of iron ore valued in excess of $A100 million was exported. The exports in 1969–70 were

valued in excess of $A291 million. The national income from the mineral export in Australia in 1966 was $A387 millions. In 1971 it rose to $A1289 millions.

The increase in national income from exports has been due to the partial lifting of embargo in December 1960 on the production and export of iron ore. The embargo had been placed in July 1938. At that time, it was considered that the reserves of high-grade iron ore were 300 million tons and that the reserves would only be sufficient for another 100 years. The relaxation of control resulted in extensive exploration, which not only increased the iron-ore reserve position, but also helped to open up vast areas for exploration and development of deposits of other minerals. Many new mineral deposits were found. For example, exploration for nickel in Australia was started in 1964, and by 1972, 388 million tons of ore had been outlined in many parts of West Australian Gold Belts. Similarly, Greenvale lateritic nickel deposits were discovered in Queensland, Australia, and are expected to go into production in 1974.

Furthermore, a number of coal and lignite deposits were discovered. The production of coal and lignite rose from 38.14 million tons in 1960 to 74 million tons in 1970 and 73 million tons in 1971.

Brazil

Brazil, in 1961, produced 10.36 million tons of iron ore and exported 5.3 million tons, increased its production to 34.77 million tons and exported 28.2 million tons in 1971. Brazil expects to export 50 million tons of iron ore by 1975 and plans are under way to export 100 million tons of iron ore by the year 1985. Steel production in Brazil amounted to 6.5 million tons in 1972, with the developments in hand, it is expected to be doubled in 1976 and further raised to 25 million tons by 1980.

Canada

The value of mineral production in Canada rose from $C1.045 billion in 1950 to $C4.93 billion in 1960 and it reached $C6.38 billion in 1972.

"A measure of the importance of mining to the Canadian economy may be found in the following figures: Over $1,150 million invested in mineral development in 1970; over $4,000 million worth of mineral products exported—almost a quarter of Canada's export trade, more than 100,000 Canadians employed in the industry; about 300 mines operating. Cities such as Sudbury, Ont. and Trail, B.C., depend almost entirely on the mineral wealth in the surrounding area, while Toronto and Calgary are financial centres for the mining and oil industries and many people employed in these cities depend on mining for their livelihood." (*Canada 1972*, p. 228–229.)

Ireland

Ireland opened her doors to foreign investments in 1960 to explore and develop its mineral wealth. As a result, Ireland started producing lead from 1964 (Table 4), zinc from 1965 (Table 5), copper from 1966 (Table 3) on a sustained basis. Lead metal content of concentrates rose from 16,100 tons in 1964 t

metal content rose from 1300 tons in 1965 to 96,250 tons in 1970 (see Table 5). Metal content of copper concentrates rose from 1139 tons in 1966 to 8229 tons in 1970, and 11,887 tons in 1971 (see Table 3). On bringing the Navan Project into production in 1975, Ireland would become a leader in the production of lead and zinc concentrates in Western Europe. At that time the Irish production of lead and zinc concentrates respectively would be 130,000 tons and 300,000 tons of metal equipment.

Poland

Copper ore production in 1960 in Poland was 2.196 million tons and it had reached a figure of 9 million tons in 1972. She is expected to produce 15 million tons of copper ore per year by 1975. The metal content of copper ore produced in 1960 was 10,700 tons and it rose to 102,000 tons in 1971 and in 1975 it is further expected to rise to 203,200 tons of copper metal per year. Similar developments have taken place in the Philippines where, in 1953, 12,700 tons of copper metal in the form of concentrates was produced and by 1962 it had risen to 54,700 tons. It has gone up to 226,312 tons in 1971.

India

We are endowed with resources of many minerals: for example, coal 85,000 million tons; iron ore 21,000 million tons; manganese ore 106 million tons; chromite 35 million tons; copper ore 300 million tons; lead and zinc ore 180 million tons; pyrite 430 million tons; bauxite 156 million tons; gypsum 1200 million tons; limestone 18,000 million tons, and magnesite 80 million tons. No doubt, as yet very large reserves of oil and a number of ferroalloy metals (barring nickel) have not yet been discovered in our country; but this does not mean that these will not be found.

Unfortunately, in our country the mineral resources have not so far added to the national wealth to the extent possible, and commensurate with the investments made. The value of mineral commodities produced in India rose from \$0.220 billion in 1960 to \$0.628 billion in 1972. (Total value 1960–72 is \$4.682 billion.) From 1960 to 1971 minerals and products, crude petroleum, metals and alloys valued at \$4.655 billion were imported. During the same period the export earnings from the minerals, mineral products, metal and metal alloys amounted to \$2.6272 billion. To import copper, lead, zinc and nickel \$1,049,416,866 were spent from 1960 to 1972 (see Table 1).

Some of the important minerals which are being produced in India are reviewed here:

Coal. Imagine the staggering energy crisis facing us with the rising fuel prices and little comfort of hoping substantial production of oil in the next 5 years. Fifth Plan targets of coal production have been fixed at 143 million tons per year. Against a target of 100 million tons for the Fourth Plan, merely 80 million tons is estimated to be achieved. India in 1972 produced only 74 million tons of coal and lignite.

Steel. The modern history of steel making in India dates back to 1907. India in 1952 produced 1.9 million tons. Our steel production increased from 1.9 million tons to 6.6 million tons in 20 years. At the end of the Fourth Plan we may produce 6.5 million tons as against a target of 11 million tons.

TABLE 1. Import of copper, lead, zinc and nickel into India from 1960 to 1972 (in metric tonnes)

Year	Copper		Lead		Zinc		Nickel	
	Quant.	Value	Quant.	Value	Quant.	Value	Quant.	Value
		Rs.		*Rs.*		*Rs.*		*Rs.*
1960	70,912	244,273,000	25,011	25,591,000	68,260	88,038,000	1507	11,934,000
1961	68,770	220,104,000	25,103	23,061,000	75,430	85,017,000	1789	14,450,000
1962	74,273	251,872,900	35,516	28,782,000	79,557	81,256,000	1572	11,982,000
1963	76,601	208,567,000	36,099	30,173,000	85,936	94,749,000	1859	15,476,000
1964	69,999	256,390,000	34,332	40,693,000	67,179	100,432,000	2467	18,884,000
1965	63,269	357,601,000	37,950	63,156,000	92,146	145,356,000	3225	24,693,000
1966	27,498	282,491,000	38,092	76,710,000	97,925	74,930,000	1219	12,222,000
1967	46,900	447,142,000	41,147	72,439,000	74,356	159,624,000	2639	36,668,000
1968	36,429	326,203,000	35,221	67,193,000	106,663	213,079,000	2241	44,442,000
1969	48,402	449,088,000	30,125	62,995,000	30,866	65,064,000	2483	50,640,000
1970	50,970	624,391,000	37,820	94,059,000	71,110	166,712,000	3064	103,024,000
1971	59,017	599,593,000	37,386	82,029,000	93,946	222,122,000	3558	105,267,000
1972	54,274	469,589,000	39,830	92,966,000	80,713	202,338,000	2343	61,287,000
	Rs. 4,757,301,000		Rs. 759,847,000		Rs. 1,698,717,000		Rs. 511,969,000	
	$ 634,306,800		$ 101,312,933		$ 226,495,600		$ 68,252,533	

TABLE 2. Production and export of iron ore (in million metric tonnes)

Year	Australia	Brazil	India	Liberia	Mauritania
1960	4.355	(5.28)	16.609 (9.08)	2.84	—
1961	5.342	10.39	18.705 (9.94)	3.25	—
1962	4.843	10.90	19.674 (8.68)	3.79	—
1963	5.515	13.39	20.602 (9.37)	7.54	1.651
1964	5.669	17.23	21.388 (10.48)	12.998	5.08
1965	6.695 (0.1)	21.08 (12.7)	23.873 (11.26)	15.959	6.28
1966*	11.553 (5.56)	23.54 (13.12)	26.733 (13.65)	16.859	7.15
1967	17.036 (N.A.)	22.65 (14.50)	25.555 (13.57)	18.224	7.45
1968	26.626 (16.66)	24.58 (15.34)	27.960 (15.63)	19.571	7.70
1969	39.406 (27.12)	26.00 (22.04)	29.566 (15.11)	21.03	8.60
1970	51.200 (41.65)	28.00 (24.05)	31.366 (21.20)	23.97	9.22
1971	61.97 (45.E)	34.77 (28.22)	33.929 (19.35)	21.55	8.60
1972			35.194 (22.10)		

*: 1966–7 figures.
E: Estimate.
Export figures in bracket in the case of Australia, Brazil, India.
Liberia and Mauritania export entire product.
Source: Mineral year books, U.S. Bureau of Mines, *The Annual Mining General 1971–72,* Mineral Statistics of India, Indian Bureau of Mines.

Iron ore. The target for 1973–4 was set at 53.4 million tons, but only 40 million are anticipated. At the end of the Third Plan only 24.5 million tons of iron ore were produced against a target of 30 million tons. Even the target of 12 million tons set for the Second Plan did not materialize, as only 10.5 million tons were produced. For the sake of comparison, the

figures of production and export of iron ore from Australia, Brazil, India, Liberia, and Mauritania are given in Table 2.

Ferroalloy and rare earth metals. We, of course, as yet, do not produce any sizeable quantity of strategic ferroalloy metals like molybdenum, nickel, tungsten, and vanadium. The demand for nickel in 1973–4 is 3751 tons, which may rise to 11,457 tons by 1978–9. Many of these metals are equally important in the atomic-energy program. Molybdenum occurs in association with the uranium copper mineralization in the Singbhum Copper Belt, copper mineralization in Malanjkhand, and copper mineralization in Khetri Belt. Besides these, there are some showings of molybdenum in Rajasthan and Tamil Nadu.

On the basis of Kansa East nickel-bearing limonite deposits, a plant to yield 4800 tons of nickel and 200 tons of cobalt per year is being set up by 1978–9 in Sukinda Orissa. Ore reserves of nickel-bearing limonite are estimated to be 15 million tons averaging 0.9–1% nickel. The exploration of Kansa East deposit was started in 1962. Nickel and molybdenum are also associated with copper uranium mineralization in the Singbhum. Tungsten is found in Degana, Rajasthan, and Agargaon in Maharashtra. Small quantities of tungsten are produced from the Degana Deposits, Rajasthan.

Non-metallic minerals. Fertilizer, the key to "Green Revolution", is produced from a number of non-metallic minerals like gypsum, phosphates, potash, etc. Their reserves are inadequately explored. The position is equally vulnerable involving not only huge amounts of foreign exchange for imports but their paucity imposes severe constraints on the development of a healthy economy.

Till after the discovery of phosphorite deposits by Dr. Richard P. Sheldon of the United States Geological Survey in Dist. Barmer, Rajasthan and Mussorie, Dehradun, U.P., were unknown in the country. His work gave impetus to the exploration of phosphates in India. As a result, phosphorite deposits in the Precambrian rocks were discovered in 1968 near Udaipur. The resources are estimated to be of the order of 70 to 100 million tons averaging 8–33% P_2O_5. The Rajasthan Government has been exploiting these deposits in a small way. A large-scale exploitation is under the consideration of the Government. Prior to the discovery of these deposits, apatite in Bihar and Andhra Pradesh were worked for internal consumption. Phosphate worth $15.5 million was imported into the country in 1971.

Pyrite deposits. 390 million tons averaging 40% sulphur of pyrite resources occur in the Amjore–Ghoga deposits of Bihar. These deposits are under exploitation; 40,886 tons of pyrite were produced in 1972, which amounted to about 22% of the planned output. Besides Amjore, pyrite deposits are also found at Saladipura in Rajasthan. The resources are estimated to be about 40 million tons averaging about 20% sulphur. These are being considered for exploitation.

Non-ferrous metals. Comparative position in regard to the production of copper, lead, and zinc from 1960 to 1972 is given in Tables 3, 4, and 5 (showing the position of India *vis-à-vis* Australia, Canada, China, Ireland, Poland, and the Philippines).

To import copper, lead, and zinc, $981,164,333 was spent from 1960 to 1972 (copper $634,306,800; lead $101,312,933; zinc $226,495,600; concentrates from 1967 to 1972 $19,049,000) (see Table 1). The cost of tin imports during 1971–2 was, respectively $10.5 million (2902 tons) and $6.0 million (1872 tons).

The demand for copper, lead, and zinc in India for 1973–4 is respectively of the order of 83,700 tons, 74,000 tons, and 131,000 tons, and in 1978–9 it is expected to be of the order of 104,120 tons (copper), 109,000 tons (lead), and 200,000 tons (zinc).

Copper. The Indian Copper Corporation Complex at Ghatsilla (recently nationalized) and now named as Ghatsilla Copper Complex, Hindustan Copper Limited, is the only copper producer in the country. Since January 1972 it has an installed copper smelting capacity of 26,500 tons per year. With the commissioning of Khetri Smelter some time in

TABLE 3. Copper content of mine production (in metric tonnes)

Year	Australia	Canada	China	India*	Ireland	Poland	Philippines
1953	38,100	229,700	8,000	(6,000)	—	4,300	12,700
1960	111,200	398,500	70,000	(8,910)	—	10,700	44,000
1961	97,200	398,332	80,000	(9,336)	—	12,100	51,900
1962	108,700	414,931	90,000	(9,781)	—	13,700	54,700
1963	114,800	415,848	90,000	(8,582)	—	13,200	63,700
1964	108,700	441,706	90,000	(9,475)	—	14,500	60,500
1965	91,800	462,473	90,000	(9,360)	—	15,100	62,700
1966	111,300	461,709	90,000	(9,438)	1,139	16,000	73,800
1967	91,800	556,389	80,000	(8,904)	3,840	16,200	85,800
1968	109,600	574,532	90,000	(9,286)	6,885	26,500	110,300
1969	124,000	600,247	100,000	(9,751)	6,400	48,300	131,400
1970	142,000	606,790	100,000	(9,311)	8,229	83,000	160,300
1971	173,200	650,729	100,000	(9,554)	11,887	122,000	188,500
1972	N.A.	722,150	N.A.	(10,264)	N.A.	N.A.	N.A.

* Copper metal produced in India.
Sources: U.N. Statistical year books, *Mineral Statistics India*, Indian Bureau of Mines; *Annual Mining Journal*, 1971, 1972.

TABLE 4. Lead content of mine production (in metric tonnes)

Year	India*	Canada	China	Ireland	Poland
1953	629	175,700	9,000	900	37,900
1960	3745	186,562	70,000	1,300	39,200
1961	3664	165,612	90,000	300	38,200
1962	2894	191,706	90,000	—	37,900
1963	3587	180,518	100,000	—	38,700
1964	3624	187,205	100,000	1,100	38,300
1965	2905	274,243	100,000	2,330	46,000
1966	2479	293,190	100,000	38,080	51,200
1967	2473	303,172	90,000	59,663	55,200
1968	1647	326,160	100,000	60,676	59,500
1969	1958	300,000	100,000	58,623	64,300
1970	1961	355,155	100,000	62,880	67,200
1971	1539	384,974	100,000	51,613	69,500
1972	2740	334,642	N.A.	50,800	N.A.

* Metal.
Source: U.N. Statistical year books; *Mineral Statistics India*, Indian Bureau of Mines: Minerals year books; U.S. Bureau of Mines.

1974, the copper smelting capacity in India would be of the order of 57,500 tons per
The indigenous production of copper metal over the 12 years has averaged about tons (see Table 3). The production in 1972 amounted to 10,264 tons. The installed cap of major end-users of copper metal is between 175,000 and 200,000 tons per year.

TABLE 5. Zinc content mine production (in metric tonnes)

Year	India	Canada	China	Ireland	Poland	Australia
1953	2400	364,560	28,000	160	161,600	243,000
1960	5383*	369,107	100,000	1,200	144,100	294,800
1961	5090	401,971	100,000	200	139,600	292,800
1962	5410	455,347	100,000	—	145,100	310,300
1963	5844	451,032	100,000	—	147,000	321,300
1964	5909	662,186	100,000	—	150,700	318,500
1965	5303	826,381	100,000	1,300	152,100	326,400
1966	4895	949,970	100,000	23,032	150,300	342,200
1967	5516	1,133,054	90,000	36,058	196,106	374,300
1968	7662	1,155,084	100,000	50,088	202,500	384,600
1969	4580	1,194,234	100,000	97,536	235,000	460,500
1970	8738	1,129,223	100,000	96,520	241,000	446,800
1971	8726	1,127,260	100,000	87,477	240,000	417,000
1972	9380	1,194,240	N.A.	N.A.	N.A.	471,700

* Metal content of concentrates.
Sources: *Mineral Statistics of India*, Indian Bureau of Mines; U.N. Statistical year books; Canada's Mineral Production Preliminary Estimate 1972; Minerals year books; U.S. Bureau of Mines.

Lead. Production of lead metal in India in 1960 was 3745 tons. It has been rapidly drop over the years. In 1971 only 1539 tons of lead were produced. Badlalamottue Lead Co Deposits are a part of the Agnigundala belt in District Guntur, Andhra Pradesh. At pre these are the only deposits of lead in the country. A number of old workings, som which date back to the eighth to eleventh century A.D., and slag heaps bear witness flourishing lead mining and smelting industry in the area in the ancient past.

The demand for lead would have to be met from importing either metal or concentr for many years. The import bill for lead from 1973 to 1979 is expected to be $262 mill Comparative position in regard to the production of lead of India *vis-à-vis* Canada, Ch Ireland, and Poland is given in Table 4.

Zinc. Zinc is produced from zinc and lead ores being mined from the Zawar Comple Mines in Rajasthan owned by Hindustan Zinc Ltd. (a public sector enterprise). The Za Mining Complex consists of Mochia, Balaria, Baroi, Zawarmala, and two unnamed perties near Zawarmala.

POTENTIAL AREAS

Geologically, Peninsular India is much like the Canadian Shield or West Australia,

Brazilian plateau, the Siberian or the African tablelands, all of these are Precambrian in age. In fact, geological history tells us of the likelihood that India once formed a part of a great land mass embracing South America, Africa, Antarctica, India, Australia, known by the Indian name of Gondwanaland. Thus there is every possibility of finding ore deposits.

For example, the geology of Kolar Gold Fields is very similar to that of the Kalgoorlie Gold Belt, West Australia, and Porcupine Gold District, Ontario, Canada.

Large deposits of nickel have been found associated with the West Australian Gold Belts. Similarly copper deposits (Porcupine Mine) and copper–zinc–lead–silver deposits (Kidd Creek) and nickel deposits (Texamont) have been found in the vicinity of Porcupine Gold District in Canada.

Nickel–copper mineralization has been reported to occur in the vicinity of Kolar Gold Fields in South India. This reported occurrence opens up vast expanse of ground for the exploration and development of nickel–copper in the various South Indian Gold Belts. Besides these, cobalt, zinc, silver, and tin may also be found (Young Indian Independence Day, 1973 issue). Occurrence of nickel–copper silver mineralization in the vicinity of the Kolar Gold Fields had been anticipated by Author (Mineral Market, December 1964; Report on visit to Australia, June 1970, HCL report).

Himalayas are a virgin territory. Most of the "porphyry" copper and molybdenum deposits occur in the Rockies of the United States, and Canada, in the Andes of South America, and in Central America. Although in these cases there was collision between oceanic and continental plates, in the case of Himalayas apparently there was a collision between two continental plates. The remnants of the ancient sea floor that separated the two plates before collision should be interesting to look for. "Porphyry" copper deposits have been found in the Sinkiang Province of China, Saindak, Pakistan, and Monywa, Burma; there is every likelihood of these being found in the Indian Himalayas. Porphyry copper deposits are being exploited from the continuation of this mobile belt in Indonesia, Papua-New Guinea. Andeman Islands are the missing link. Moreover, both extremities of this belt are producers of tin tungsten and molybdenum (in short supply in our country). One can realize the importance of the geology of Andeman and Nicobar Islands, which has been neglected so far. We have a Malanjkhand porphyry copper deposit of Precambrian age in Madhya Pradesh (implying if one why not others), which was identified by the writer in 1970. This has opened up a vast expanse of Precambrian area in India for the exploration of porphyry copper mineralization.

Porphyry copper mineralization of Precambrian age is being explored by the Bressard Mining Group of Montreal, Canada. This is a low-grade deposit (0.25% copper). But it is a resource for future development and use of mankind.

Discovery of Precambrian phosphorites in Rajasthan, India, resulting in identification of phosphorites of Precambrian age in Brazil. Therefore, the study of Precambrian rocks of Canada, Australia, Africa, and the U.S.S.R. may result in additional discoveries of phosphorites.

Exploration of vast traces of Precambrian in India, Saudi Arabia, Africa (Egypt, Sudan, Ethiopia, Kenya, Tanzania, Mozambique, Lesotho, Botswana, Ivory Coast, Senegal, Liberia, etc.), and Brazil may lead to discovery of many new mineral deposits hitherto unknown. A better understanding of the Precambrian metallogenic processes and history of these areas coupled with increased pace of exploration and development activity is needed.

NEED TO INCREASE THE SPEED OF EXPLORATION AND DEVELOPMENT WORK

During the sixties a number of very large open pit and underground metal mines in many parts of the world have been brought into full production even in inaccessible areas in a span of about 5 to 7 years from the date of discovery. Average lead time from discovery to production of metal is 5 years. For example:

Indonesia. Ertsberg copper mine (2.7 million tons per year—6 years).

Ireland. Tynagah (2000 tons per day of lead–zinc–copper—5 years); Mogul mine (1750 TPD of lead–zinc–silver—5 years); Navan (7500 TPD of zinc–lead—5 years).

Western Australia. Kambalda (nickel—2 years).

Canada. Heath steel mine (1500 TPD of ore—4 years); Madelline mine (2500 TPD of copper ore—4½ years); Mattagami mine (3500 TPD of zinc–copper–silver ore—6 years); Whalesback mine (1500 TPD of copper ore—4 years, raised to 2000 TPD in the next 2 years); Kidd Creek mine (9000 TPD of zinc–copper ore—4 years); Thompson mine (5000 TPD nickel–copper ore—5 years); Ming mine (2 years); Gibraltar copper mine (36,000 TPD—4 years).

Greenland. Marmorilik deposit (3000 TPD—4 years); Liberia–Lamace iron ore (7 million tons per year—7 years).

Peru. The government signed an agreement with the Southern Peru Corporation in December 1969 for the development of an open pit copper mine at Cuajone, construction of a mill, necessary transport, housing and other installation, to produce 140,000 tons of blister copper in 6½ years' time.

TABLE 6. Comparative statement of exploration work done at Khetri and Kolihan Mines (India), and Thompson Mine (Canada)

	Khetri Mine	Kolihan Mine	Thompson Mine
Air magnetometer surveying	Nil	Nil	128,747 line km
Air electromagnetic surveying	Nil	Nil	112,654 line km
Ground electromagnetic surveying	Nil	Nil	594,360 stations
Ground magnetic surveying	Nil	Nil	540,000 stations
Diamond drilling			
Surface	30,603 meters	10,560 meters[a]	597,060 meters[c]
Underground	15,997 meters	5,628 meters[a]	162,154 meters
Mine development		6,227 meters[a,b]	
Shafts	800 meters		1738 meters
Raises			10,363 meters
Drifts and Cross cuts (Raises, Drifts and Cross cuts)	13,873 meters[b]		39,624 meters
Daily production	7000 TPD	3000 TPD	5000 TPD
Proved reserves	1.0 million tonnes	0.5 million tonnes	25 million tonnes
Discovery hole	1957	1959	1956
Date of production	?	?	1961
Capital expenditure	Rs. 1200 million up to 1972-3		Rs. 1050 million up to 1961

[a] Till November 1970.
[b] Includes all kinds of sundry works.
[c] Includes Mock meterage.
Note. Mine development in 1970, 1971, 1972 respectively amounted to 2176 M, 4260 M, and 3917 M.

Poland. Lubin (4.5 million tons of ore per year—5 years); Polkowic (4.5 million tons of ore per year—5 years); Rudna (9 million tons per year—7 years). Lubin and Polkowic have already attained full production. Rudna is under development.

Many of the projects which came into production in the early sixties are undergoing expansions. For example, Thompson Nickel Operation, Canada, which was commissioned in 1961 to yield 25,000 s. tons of nickel per year, reached a capacity of 85,000 s. tons per year in 1971. To do this the milling capacity was tripled, the smelter capacity was doubled, the refining capacity was increased and a number of new mines were prepared. All these staggering expansions were achieved in only a decade (1961–71). On the other hand, we take about 18–31 years to explore and reach optimum production. Table 6 gives a comparative statement of exploration work done at Khetri and Kolihan mines (India) and Thompson mine, Canada. It will be observed that at Khetri and Kolihan mines the quantity of work done over a period of 14 years is little in comparison to what was achieved in 5 years.

Table 7 gives a comparison of the quantity of work done at La Argentier, Gortdrums, Bandlamottu, Nallakonda, and Ming deposits. La Argentier (France) and Gortdrums (Ireland) came into production in about 5 to 6 years, and Ming (Canada) in 2 years. Bandlamottu and Nallakonda have been under exploration for the past 20 years.

TABLE 7. Comparative statement of exploration work done at La Argentier, Gortdrums, Bandlamottu, Nallakonda, and Ming Deposits

	La Argentier lead-zinc mine of De Pennaroya France	Gortdrums copper-silver at Tipperary, Ireland	Bandlamottu copper-lead project, India	Nallakonda copper project, India	Ming Mine Newfoundland, Canada
Ore reserves in million tonnes	7.5	4.2	11.5	4.9	0.928
Diamond drilling in meters	35,052	12,129	19,497	14,965	11,798
Exploratory mine development in meters	—	—	2,600	750	—
Geophysical surveys	Gravity 15 sq. miles	—	—	—	Airbone EM,I.P.
Geochemical surveys	14,000 samples	Nil	—	—	Soil samples at 15 &30 m intervals
Depth of ore body in meters	145 to 305	100 580 & 122 wide	245 to 457 1280	250 2000	214 182
Daily production	1850 tons	1500 TPD	?	?	600
Grade	Pb 4% Zinc 0.75% Ag 2.5 oz/tonne	Cu 1.19% Ag 0.75 oz per ton	Pb 6.16%	Cu 1.487%	Cu 2.67%
Drill spacing in meters	30	30	101	101	?
Tonnes per meter drilled	215	347	591	328	79
Tonnes per intersection	18,150	42,000	127,325	68,186	7356
Period	1958–64	1962–7	1950–73	1950–73	Sept. 1970–June 1971 Mine in product in 1972

Ore production from the underground metal mines in countries such as Canada, U.S.A., Australia, France, and Ireland in the last 20 years has gone up from about 6 tons to 10–12 tons of ore per man shift (OMS) and even up to 40 tons per man shift.

In India, ore production from the underground mines has remained 0.15 ton (Kolar) to 0.8 ton per man shift over the same period. Similarly, the production from many open pit mines in a number of countries averages between 100 and 200 tons per man shift whereas the Indian average has not exceeded even 10 tons per man shift.

It is necessary to increase the pace of exploration and development activity in the under-development countries so that deposits are explored and developed and brought into production quickly so that these countries are able to offset the import bills and meet the demands of their populations.

For instance, India needs to produce about 143 million tons of coal by 1978–9. To produce this coal the resources of coal have to be developed, for which 1.2 million metres of diamond drilling is necessary. If this drilling is to be effective, then all this should be completed in 2 years, otherwise India will not only be short of coal in 1978–9, but will be terribly short of it in 1983–4.

Canadian mining industry drills about a million meters per year in hard rocks, therefore, to drill 1.2 million meters in coal in about 2 years is not a big job. To achieve this the drilling speed has to be increased from about 700 meters per year to about 2000 to 3000 meters.

FINANCIAL ARRANGEMENTS

We in India have adopted a basically sound approach in deciding to proceed with the exploitation of the major minerals in the public sector. These ventures require very vast outlays of money (including foreign exchange) and raw materials. It is only sound thinking that such enterprises should be developed on a national basis in consonance with the overall economic plan of development of the country.

Exploitation of mineral resources provides revenue for the growth of any nation. Many governments, even in highly developed countries, to find funds for development, are veering around to the point of taking direct or indirect control of the mineral industry. Recent examples are the laws about to be enacted or which have been enacted by the provincial and federal governments in Canada, Australia, and Ireland. This trend is going to continue and increase in the years to come. Many more governments are going to follow this course.

The public sector enterprises certainly can achieve their targets and also make an efficient showing of the economic picture. But for that they have to get out of the grip of bureaucratic approach. All these enterprises need to be run on strictly controlled and efficient principles of good business and sound technological approach.

Some of the most severe handicaps in the industrial enterprises in the public sector can be the lack of motivation and professional integrity and intellectual honesty of many individuals in responsible positions. Each industry has its own special problems and only those who have been educated, trained, and experienced and have made substantial contributions in that special discipline should be at the helm of affairs.

In any planned economy the targets to be achieved have to be realistic. The progress attained in the projects has to be commensurate with the targets. A plethora of inefficient incompetent operations has no place in this concept.

The targets fixed can be achieved, no doubt, with extensive inputs of money, but no

amount of financial inputs can get us very far as long as the people who work towards those targets do not know their jobs.

In order to elevate the economy, drastic measures need to be taken to achieve the targets. Many of the less-developed countries are endowed with adequate resources, which if developed could meet their modest needs. Exploration of the mineral wealth in these countries has only touched fringes so far and there are very good possibilities of discovering a great deal more of subterranean mineral wealth. To do this efficiently, there are some alternative suggestions:

(a) Bring consultants and experts under various programs. The experts and consultants come under various programs give useful advice in the early stages of their involvement, but later realize it is in their own interest to give the advice as required by the clients and not what is needed. Most of these consultants and experts are used by the individuals in authority for their own purposes and benefits. In my opinion this is not a very good solution.

(b) To allow foreigners to invest in their mineral industry and bring know-how along with them. Some quarters may feel this is a step against the national interest.

Such steps have been initiated by some of the developed and less-developed countries like China, Poland, and the Soviet Union.

For example, China is negotiating with Japan and the U.K. for the establishment of steel plants and an imperial zinc smelter. She is also looking for assistance in offshore oil exploration.

The copper industry in Poland is of recent origin. Copper ore production in Poland in 1960 was 2.2 million tons. In 1972 it had reached 9 million tons, and by 1975 the production of copper ore is expected to be of the order of 15 million tons.

Similarly, the Soviet Union for the past several years has been negotiating with the U.S.A., the U.K., France, Germany, and Japan for joint ventures to develop Orenburg nickel in Southern Urals, Udokan copper deposits northeast of Lake Baikal, natural gas in Siberia, fertilizer industry and steel industry, development of Chulman coal fields, and development of ports on the Pacific Coast in exchange for her raw materials.

The Soviet Union has signed an agreement with Occidental Petroleum Corporation to develop a fertilizer complex at Kuibyshev, 500 miles south-east of Moscow. Occidental will provide large quantities of super phosphoric acid and with Bechtil Corporation build the complex. In exchange, Occidental will market abroad liquid ammonia, potash, and urea.

Besides there have been negotiations between the Soviet Union and a number of American companies and Japanese interests to develop natural gas fields in Siberia. These multi-billion agreements provide for the sale of gas to Japan and the U.S.A.

Various countries, regardless of the political complexion of their government, require capital, the latest technology, as well as technicians to develop certain projects. The less-developed countries in their self-interest should be looking for the technology of tomorrow and not yesterday, and should benefit from the experience gained by other countries.

We may not be able to change the political systems of the governments themselves, but ways and means can be found to live and work under these systems.

Developed countries have very sophisticated technologies which the less-developed countries need to adopt rapidly to develop their mineral resources to meet the needs and aspirations of their growing populations. These countries cannot afford to repeat in series the mistakes made in the process of developing highly sophisticated technologies.

To get the latest technologies AID is not the answer. The less-developed countries should

learn to pay as they go along, and the developed countries should be willing to share the technological development by transferring the latest technologies and by paying higher prices for the raw materials. For the transfer of technologies the following modes are suggested:

Production-sharing

The foreign company, employing its own risk capital, equipment, and expertise, is granted an exclusive exploration permit to explore for ore within the confines of a predetermined area of nominal size. If marketable ore is found, a company-financed and sponsored feasibility study is presented to the government for consideration. If the government concurs with all exploration conducted, and with the findings of the study, the company loans adequate funds for development to the government against an eventual repayment with interest.

The funds loaned include money spent for exploration plus that which is required for the development of the contained ore bodies; the mine and its facilities; and all necessary beneficiation processing smelting plants. The ore discovered and developed for mining is the property of the government. The company, however, has the first charge on the ore to amortize its exploration development construction costs. This is referred to as "cost ore", and may in part be sold back to the government (for cash reimbursement) for domestic consumption or in part exported; or it may all go either to domestic consumption or all to exports, as the government prefers under the existing demand requirements.

After this, the government assigns a predetermined reserve to itself (to be negotiated—but 50% or more by volume). The company may purchase the ore produced from the remainder at a negotiated price, that is, in effect about 50% of profit calculated on a realized price. To the company, this would be "profit ore", a portion of which may also be invested in additional exploratory efforts, with matching funds from the government, in new areas.

The duration of a contract may be of any fair and equitable period of time, but 20–25 years subsequent to the beginning of mining and processing would be desirable to the company and to the government specifically to build a self-perpetuating in-country expertise.

Service contract

This approach begins generally as if it were a production-sharing contract in that the foreign company assumes the risk of exploration, feasibility study, and the cost of plant construction. However, at this point, it reverts solely to a "pay-back" arrangement to the company-cost plus a fair profit. It resembles the turnkey type of operation, except that the contractor normally remains active on the project for a sufficient number of years in a supervisory capacity to adequately work out teething troubles in the mine and plant(s) and to properly train local administrators and technicians in the operation and management of the mine and included plant(s); and to establish a workable spare (and replacement) parts supply network for normal-roster mine and plant equipment.

The service contract is essentially a "get-in-and-get-out" agreement for a contractor. The profit that he would demand may be higher than that which could be negotiated through the production-sharing approach. However, it may be to the government's advantage to be willing to pay more on the short run to gain an indigenous mineral production rapidly

and to thus quickly realize important savings in foreign exchange through import substitutions.

Australia, Brazil, Indonesia, and Ireland were closed-door societies to outsiders in mineral exploitation. In the sixties these countries opened their doors to outsiders for mineral exploration and development. As a result, spectacular developments have taken place in these countries.

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DISCUSSION

BROWN: Thank you very much, Dr. Sikka. I would now like to call for general discussion of the papers and discussion on investment requirement. Does anyone have a question or a comment?

RUIZ: I'd like to make some comments on the last presented paper of Dr. Sikka. I agree completely with their conclusions. Our country is also an underdeveloped country that has very large copper reserves and resources that we need to develop as soon as possible to get our economy in a better way. For example, our actual production of copper is 900,000 tons of copper per year. To maintain the percentage of production in world production, we need at least to invest in the next 6 to 8 years something between 1500 million dollars to 2000 million dollars. So that's impossible for us to get that large amount of money and we have just now at least three very large deposits in the medium stage of exploration that could increase our actual production of copper in some 300,000 tons per year. Our government right now is trying to get foreign investments for the developing of these known deposits. As I said before, besides those known deposits we have very good chance to find much more reserves of copper. There are two formulas under which the foreign investments can be achieved. One is a joint venture with the participation of the country in a determined percentage of the capital, and in which the foreign company facilitates the financing and also technology for the development, assuring in this way that the project would be on stream at a proper time. Under these programs, the foreign party has the obligation to train our own technical people so that in a short period of time they will be in a position to direct the operations. Actually we have trained people in copper mining and metallurgy, but right now they are engaged in the operations of the big nationalized mines. The other way to get foreign investments is through "Contracts of operation". In that case the property of the mining concession remains in Chilean hands—either the government and/or private individuals—and the foreign company brings all the capital needed and operates the mines. After a certain period of time—10, 15 or 20 years—they leave all the installations to the government and/or private owners of the concessions; at the same time they have to train our people for the following up of the operations. The proceeds of the copper produced in the above-mentioned period are first assigned to repay the investment and the cost of production and the profits are divided on an agreed percentage between the country and the foreign company.

So I agree with Dr. Sikka that for underdeveloped countries that are very rich in mineral wealth, I think those are the best ways to develop this wealth in time and in the proportion related with—in the case of my country—the copper resources of our land. Thank you.

BROWN: Any other comments or questions? Might I ask Dr. Sikka. . . . I was somewhat surprised when you stated in effect that the cost of the development of a new mine in a country such as India is not appreciably different from the cost of development in one of the more industrially developed countries. Is it true that the availability of large quantities of relatively inexpensive labour has no effect upon development costs?

SIKKA: You see, we apply five people—you apply one. This is the amount. The only difference is, we will apply five or maybe ten people to do the same job which you do with one, so it comes to the same amount in the end. This is the only difference. I have not found . . . we have made all the analyses and various projects and come up with the same figure. The only thing the number of people employed gets increased. Sometimes we don't need all of them. In some steel plants we have 15,000 or 16,000 people sitting, doing a job when there's really no job to do. But they're there, because of practices. We can reduce, maybe we can even bring down the costs. But you add the cost per ton of labour and ours would be roughly the same.

WALKER: In listening to the speakers a potential conflict comes to mind. Dr. Sikka just spoke about the need of some countries to develop resources quickly. Other speakers have talked about these resources as limited and the need for their conservative use and development. It seems to depend upon your particular situation whether you need to rapidly develop or conserve these resources. In countries where you must conserve resources, you're concerned about resource depletion and adversely affecting the economy that you've already developed. In country's where you need to develop resources, you are trying to expand a very limited economy. Because each countrie's preoccupation is probably so strong with their own crisis problem—either that of developing or conserving—they are not likely going to be able to deal effectively with the problem of the opposite need. I think we will need to consider how to deal with this conflict.

CLOUD: I'd simply like to respond to the last comment. I don't see the conflict, although I think I see why you express this conclusion. When I talk about conservation, for instance, I am not talking about conservation in the sense of leaving the stuff in the ground and not taking any more out. I'm talking about reducing the levels of material consumption of already affluent peoples in society, about making more effective and conserving use of materials, and about reducing waste, and people of like mind would only applaud and like to assist the efforts of the poorer countries to discover and develop their resources in terms of improving the general level of living of the peoples of their societies. There is not a single answer for the world as a whole. More affluent societies and those which have dipped deeply into their reserves of raw materials need more conserving practices, while countries that are in the process of trying to develop their economies need all the help they can get in doing so.

WALKER: Ideally there is no conflict. Dr. Cloud's view is a great goal, but I believe there will be great difficulty in its implementation. If I might speak about this conflict in another way—a goal in the United States is to develop fuel resources very quickly. One way to accomplish this goal may be by strip-mining, which disrupts the soil surface and drainage streams and which creates a resource utilizing reclamation problem.

McKELVEY: I also interpreted what Mr. Walker said in the same way Dr. Cloud did and I'm not sure now that I understand what his concern is. There certainly is, of course, a conflict in the development of natural resources. Often the development of one does lead to the sacrifice—at least on a temporary basis—of another. That doesn't necessarily need to be true over time—the multiple use of land in the sequential sense is possible, although not achievable perhaps in every case. With respect to the conflict in development vs. conservation as I first thought you were speaking about and Dr. Cloud did also, I simply wanted to stress too that in my own conclusion I referred to the need for developed countries to begin searching for ways to taper off their increase, their rate of increase in consumption of energy and raw materials and I wanted to stress too that I don't put the developing countries in this second category. For one thing, even though their rate of increase in consumption of energy and raw materials exceeds by far that of the developed countries at the present time, their total consumption of raw materials and energy is still very small. They are not contributing to the problem in the way that the developed countries are presently.

RUIZ: In relation with the comment of Dr. Walker, I think that some of the underdeveloped countries have unbalanced amounts of resources. For example, if it is true that my calculation that the total copper resources of Chile are in the range of 450 million tons, at the actual level of production of less than 1 million tons per year, we are going to have copper for 450 years. According to some figures, the copper resources of the world are going to be exhausted in some 50 years. So if we don't rush our copper exploitation, we are going to have these resources underground without any use.

CLOUD: I would simply like to make two brief notations. One is in reference to the response about trade-offs, the environmental impacts and so on. I'm sure we all agree that the time is more than overdue to think and speak of costs not as dollars alone but as total costs. We must consider all the trade-offs, including all aspects of the protection and restoration of the environment where mineral resource exploitation and exploration in any way defaces it. The other thing, just to amplify slightly my remarks about assisting the underdeveloped countries, is that I want to emphasize that one of the most important things the underdeveloped countries can do to help themselves is to get their rates of population growth under control so that gains made are not wiped out by additional mouths to feed and bodies to house and clothe.

FACTORS LIMITING THE FUTURE PRIMARY MINERAL SUPPLY SYSTEM

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Minerals have long been classified as "non-renewable" resources. This characterization is based on the idea that new mineral deposits are created through geologic processes so slowly that they have no perceptible impact on the mineral supply system. The term also implies that at some point the supply of minerals may cease. On the other hand, renewable resources include such resources as food products, which are renewed each year by the agricultural cycle, and water, which is renewed periodically by the evaporation–precipitation cycle. This characterization of minerals as "non-renewable" obscures the dynamics of the mineral supply system. The fact is our current stock of minerals must be continually renewed. We only find a small amount of mineral *reserves* at a time, and as they continually are being used up, they must continually be *renewed* by efforts of both government and mining industry, by both scientific and technologic research and by both exploration and mine development. So mineral reserves, like food products, are renewable and it takes effort to renew them.

Mineral reserves are renewed by discovery of *new* deposits and the development of *new* mineral technology for application on subeconomic deposits. Thus, man creates and drives his mineral supply system by (1) finding mineral deposits, (2) where they can be legally exploited, (3) with mining and processing technology, (4) at a profit, and (5) with socially and biologically tolerable damage to the environment. These five necessary conditions to mineral supply impose potential limitations to their availability. Hence, the factors limiting the future primary mineral supply system are: (1) geologic availability, (2) political availability, (3) technologic availability, (4) economic availability, and (5) environmental availability.

Geologic availability. The success of finding new mineral deposits depends ultimately on the *geologic availability* of deposits. There is a finite limit to mineral deposits of any given type and grade, and beyond that limit no further such deposits are available. However, the geologic availability of minerals is only poorly known with the present information. Clearly, their availability lies between the present mineral *reserve* estimates, which exclude the deposits yet to be found and the deposits that are presently subeconomic, on the one hand and the estimates of the total amount of minerals present in the earth's crust which is dominantly made up of ordinary rock containing only tiny amounts of minerals on the other. This gap of uncertainty is too large for meaningful forecasting and planning. It is

imperative that man invests the scientific effort required to appraise our resources more accurately in order to answer more satisfactorily the question of potential future supply. But in spite of the lack of accurate estimates, it can be said that probably the quantities of many minerals in both known and undiscovered deposits economic to develop with *present* technology are insufficient to last through the foreseeable future at the increasing rates of mining.

Political availability. The political availability of mineral deposits is a factor that directly influences mineral supply. Legal exploration and exploitation of minerals depend on it and is a function of:

1. National mining legislation relating to permission to explore.
2. International regulations or lack of regulations in international areas such as the seabeds and Antarctica.
3. Withdrawal of lands from mineral entry because of other land use such as cities, parks, wildlife, and mineral reserves.
4. Splintering of land into small parcel ownership resulting in impracticality of putting together mining tracts.

Technologic availability. The level of primary mineral supply is a function of the level of exploration and exploitation technology. The amount of minerals that can be found in the earth's crust is smaller than the amount of minerals that occur in crust, and depends in part on the effectiveness of exploration technology, which includes the technology of geochemical and geophysical prospecting, the technology of geologic direct and remote sensing, and the technology of drilling and geologic interpretation. Likewise, the amount of minerals that can be recovered is smaller than the amount that occurs in the crust and depends on the effectiveness of exploitation technology, which includes the technology of mining, milling, refining, and transporting mineralized rock.

Economic availability is a function of the profitability of mineral production, which is the value of the mineral product over the cost of finding, measuring, mining, milling, refining, and transporting the ore. Any deposit regardless how small, low grade, remote, deeply buried, or well hidden, could be found, and its minerals produced, if enough effort is expended. But only that amount of effort commensurate with the value of the minerals produced will be expended. This places a limit on the amount of minerals that will eventually be produced. Although many factors influence the costs of mineral exploration and production, the most important is the cost of energy. Mineral exploration and production is energy intensive, particularly as the potential mineral deposits become more remote, deeper, lower grade, and more tightly bound chemically to anions and complex anions, and as more reclamation of mined areas and control of pollution of mineral exploitation is required. The most energy sensitive of these factors is probably grade. Barring development of extremely cheap energy supplies, it appears that there are impassable lower economic limits to the availability of mineral deposits. If the current upward cost of energy continues, it is inevitable that some mineral deposits that are now marginally economic will become uneconomic and be removed from reserves.

Another adverse factor of economic availability is the increasing alternate land values of mineralized land as land becomes more and more in demand. If the value of land used for recreational resorts, transportation corridors, cities and towns, and agriculture where

restoration after mining is not feasible, is larger than the value of minerals contained in the land, mineral development would be foreclosed, at least until the values reverse.

Environmental availability. Local and regional environmental degradation are rising and possibly are approaching levels that in some cases are biologically intolerable. Only a part of this change is due to mineral exploitation, of course, but general restrictions on further pollution would affect the mineral industry along with other industries. Long-term environmental availability of mineral products is dependent on the following general conditions:

1. The pollution levels of mining and mineral production are in long-term equilibrium with the natural environment, so that the biosphere continues to exist at acceptable levels.
2. The sacrifice of land to mining is only at levels that do not destroy the long-term renewable natural resource supply necessary to man.
3. The pollution and land-sacrifice levels above are aesthetically acceptable to the governing units involved.
4. The value of the mineral production causing the pollution and land-sacrifice levels above is greater than the unrealized long-term values of non-mineral natural resources foregone.

These five availability factors are not independent of each other. The predicted decrease in the geologic availability of minerals would strongly impact the other factors if mineral supply is kept constant or increased. It would require increased political availability with subsequent social disruptions. It would require increased technologic availability necessitating greater investments in R & D. It would decrease economic availability and thereby require larger investment of human and capital resources, assuming energy costs remain constant or increase. And it would require an increase of environmental availability which implies a lowering of environmental safeguards. In like manner, changes of any of the other availability factors would set off waves of interference in the other factors. A corollary to this proposition is that any one of these availability factors may act as a limit to the world mineral supply system.

The present status of knowledge of these factors makes an accurate assessment of the dynamics of the mineral supply system impossible. It is of first-order importance to improve this knowledge. It is imperative that a substantial program of scientific, technologic, legal, political, and economic research be addressed to these problems on a worldwide basis. It is also imperative to construct a computerized model of the world mineral supply system to investigate quantitatively the interaction of controlling factors. In the meantime, in the absence of dramatic breakthroughs in geologic, technologic, or economic availability barriers, the world supply of primary minerals should be carefully conserved.

I would like to raise a question to discuss for the remaining time. I think it would be worthwhile for the conference if the feeling of the experts in this room were explored as to the future supply of minerals—cornucopia or collapse? or in between?

I will start with my favorite hypothesis or scenario, which is as follows:

1. To meet demand for minerals, we would have to find increasing amounts of deposits which themselves become ever harder to find. Even with *maximum* science and technology which I think unlikely to be achieved, this effort will fall short.

2. To meet demand, we would have to produce our minerals from increasingly leaner and more remote deposits. Even with maximum technology, *this* effort will fall short.

3. Mineral prices will rise and an increasing amount of society's effort will go into mineral supply.

4. The growth rate of mineral supply will level off or decrease, and in the long term supply itself will probably decrease.

5. I think this process will begin slowly so that the start will not be really evident and the start will come earlier for some minerals than others.

6. Therefore, the burgeoning demand of man for minerals to increase and more equitably distribute his level of living will not be met and social, political, and economic institutions will have to adjust accordingly. R13439

DISCUSSION

R. P. SHELDON: The group discussed three aspects of resource availability and depletion. First, what is the potential of world mineral resources? And how well do we understand them? Second, what investments must be made by mankind to win them from the crust of the earth? And third, what is the future prospect for the world mineral demand being met by primary supply?

Taking these up in order. The world mineral supply is directly derived from the *known* reserves of minerals, that is, those deposits identified and measured and economically profitable to mine. The reserve of most minerals will last only several decades, but this is no cause for alarm as mining companies usually only develop a reserve large enough to justify their investment, and they add to reserves only at about the rate that they mine.

A part of *potential* reserves are the mineralized rock from which the *known* reserves are discovered. They are a different thing entirely. They are undiscovered, unmeasured, and unevaluated. Estimates of their size must be predicted by geologists using their scientific tools. Such estimates have been made, albeit crudely and with very little data, and these preliminary results *are* cause for alarm. In general these potential reserves are about equal to the known reserves, or are larger only by a factor of 2 or 3. It should be realized though that these potential reserves are conservatively estimated, and this estimate can be expected to increase with scientific advance and collection of more data.

Also, it should be kept in mind that the other part of potential reserves includes rock that is presently uneconomic to mine, but can be mined in the future. So another way we can extend our primary supply is to learn how to economically extract minerals from those deposits that at the present time cannot be mined at a profit. This takes research and development in order to improve extractive and refining technology. The increased amount of minerals that this process will add has not been estimated at all. Its size depends on both the success of the R & D effort and the amount of subeconomic mineralized rock that exists as well as the price of minerals. Even though much of this R & D effort will be successful and even though much subeconomic mineralized rock exists, it seems likely that the increased mineral supply from this source is limited, at least for many minerals, for the following reasons.

It appears that the tonnage of some and perhaps most minerals does not increase as the grade of the ore decreases, as was thought in the past. In fact, the tonnage may decrease as was shown to be the case for the copper deposits of Chile, a major source of the world's copper. Thus, subeconomic resources may not be much larger than the economic resources, contrary to the assumptions of some modern economic models, and this may place a limit on the supply of some primary minerals.

How about improvements of technology? The exploitation of minerals is energy intensive. In fact, the availability of cheap energy was a major factor in the recent technologic advance. It has been shown that as the grade of deposits decreases, and their depth and remoteness increase, energy costs go up exponentially. This combined with escalating world energy prices also may place a limit on the future primary mineral supply.

The second major subject of concern to the session was the investments required to bring resources into production.

It was felt that investments were needed to help the functioning of world mineral trade. The developed countries of the world are using their own minerals at an increasing rate as well as importing increasing amounts of minerals from the developing countries. Also, mineral processing, which greatly enhances the value of minerals, generally is done in the developed countries. This is causing severe strains in international trade and relations. The question of whether it is equitable for the rich countries to use most of the world's minerals at a cost of only the raw materials must be answered. Confrontation is to the advantage of neither side. Cooperation on an equitable basis is imperative. Thus an investment of statesmanship on the part of world leaders is vital. Improvements must be made in world financial institutions, international mineral treaties, international import and export regulations, and financial and development policies of both rich and poor countries if cooperative international mineral trade is to take the place of confrontation.

Investments are needed to appraise the potential of world mineral supply. The countries of the world need to know what resources they have and how they might find and produce them. Important investments for these purposes include:

1. An increased research and development effort in mineral science and technology as we have seen. It is particularly critical to ensure that this body of knowledge is transferred to the developing countries.
2. A worldwide effort in mineral resource appraisal consisting of more geologic mapping and the building of a world mineral data bank.

To accomplish this, the geologic and mining research institutions of the world governments need to be strengthened.

Investments are needed to increase the mineral production capacity of the nations of the world if their mineral potential is to be realized. Important investments in this area include:

1. The training of mineral scientists and engineers to meet the present world manpower shortages in these critical fields.

2. In the developing countries, investment in training managers of mining operations is especially needed to decrease the lag time between discovery of a mineral deposit and its production.
3. Finally, the investment capital required to increase the production capacity in all parts of the world is enormous. Where is this capital to come from? The mining companies of the rich nations are making low profits relative to other industries and are presently incapable of generating their own capital. In the poor countries, even government capital is insufficient. Despite the source of the capital, it must be found and invested if the world mineral production capacity is to increase.

The final topic discussed in our session was the prospect for world demand for minerals to be met in the future. It was generally concluded that at the present exponential increase of demand, there is no chance it will be met. Exponential growth cannot last in a finite world.

This does not mean that growth of supply cannot occur, however. Man creates and drives his mineral supply system by (1) finding mineral deposits (2) where they can be legally exploited, (3) with available, mining and processing technology, (4) at a profit, and (5) with damage to the environment that is socially and biologically tolerable. There is little doubt that he will achieve additional success in this process, but at the same time these five necessary conditions to mineral supply impose potential limitations to their availability. Hence the five factors limiting the future primary mineral supply system are geologic, political, technologic, economic, and environmental.

The present status of knowledge of these factors makes an accurate prediction of future mineral supply impossible. Therefore, it is of first-order importance to improve this knowledge. It is imperative that a substantial program of scientific, technologic, legal, political, and economic research be addressed to these problems on a worldwide basis. It is imperative to construct a computerized model of the world mineral supply system to investigate the interaction of controlling factors.

In the absence of such a model, the following scenario, intuitively developed from existing trends, was suggested.

To meet demand for minerals, man would have to find increasing amounts of deposits, which themselves become ever harder to find. Even with maximum science and technology, which seems unlikely to be achieved, this effort will fall short.

To meet demand, we would have to produce our minerals from increasingly leaner, deeper, and more remote deposits. Even with maximum technology, this effort will fall short.

Mineral prices will rise, and an increasing amount of society's efforts will go into supplying its minerals. The growth rate of mineral supply will level off or decrease, and in the long term be reversed so that supply itself will probably decrease.

This process probably will begin slowly so that the start will not be readily apparent, and the start will come earlier for some minerals than others.

Therefore, burgeoning demand of man for minerals will not be met, his desires to raise his level of living and extend it to all men will not be satisfied, and social, political and economic institutions will have to adjust accordingly.

Mr. Chairman, these were the general topics discussed in our session.

BROWN: Thank you very much. I will now open the floor, not only for discussion of Dr. Sheldon's paper directly and the questions he raises, but to the morning discussions as a whole.

McLAREN: I want to make four brief points which range over various papers. First of all a comment on Mr. Bercè's remarks about the availability of land surface for exploration. This is a major and important object of research. I would point out that geochemistry of water and remote sensing systems now being developed do in fact get around the difficulty. The technological research required in both systems are first priority in many countries, and should be. The second point is to discuss the debate raised by Cloud, Sheldon, McKelvey and others, which is of course the real debate about what we're here for: shortage versus the cornucopias. There was an article recently in *The Economist* which suggested that mineral resources would endure for 100,000 years. On the other side, we must understand that the inexorable advance of exponential growth cuts down our presently available resources to a relatively few years. The dangers are here and now. If we regulate our own usage, nevertheless the population of the world will increase. As it will double in 30 years or so, then growth in the use of minerals will continue, even if we limit usage to its present per capital. But in addition we must increase usage in the underdeveloped world, thereby inducing double exponential growth.

The third point is on finance, which in the broadest sense means the resources available to carry out a job, not just money. Whatever monetary system one may adopt, the cost of energy required for mineral production will be the controlling factor. We are facing immediately financial outlays which are so staggering that one wonders if they can in fact support the production of energy which we shall require. In my own country, in Canada, for instance, it seems quite impossible that we can find the kind of money needed to build a pipeline from either Prudhoe Bay or the Mackenzie Delta or both and, from the Arctic Islands; that we can carry out the exploitation of the oil sands which cost more than 1 billion dollars for 100,000 barrels of oil a day; and also carry out the enormously expensive exploration and exploitation of the offshore oil in the Arctic and Labrador. So that it seems to me that the limitations on increasing production

Chapter II

EFFECTS OF RECYCLING UPON WATER AND AGRICULTURE

CONTENTS

LE SOL ET LE RECYCLAGE DES ELEMENTS

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Dans toute étude des ressources naturelles le sol a sa place, et une place importante.

Soutien et facteur du développement de la végétation et de nombreux micro-organismes, tant végétaux qu'animaux, il est un facteur essentiel dans la production d'aliments et de biens très divers, concernant l'habillement, la construction, les matières plastiques, etc.... Il intervient, de même, indirectement, dans le maintien des caractéristiques fondamentales du climat, de l'atmosphère ainsi que dans l'extension des zones de sport, de récréation, de loisirs, dont la nécessité apparait sans cesse davantage. Il est indirectement l'un des constituants permettant à l'homme d'utiliser une quantite illimitée, d'énergie solaire. Il peut etre également un materiau épurateur vis à vis de divers types de polluants, ou être utilise dans des processus de recyclage de différents matériaux.

Il est donc essentiel de maintenir le sol dans un état tel qu'il puisse remplir ces différentes fonctions.

Il peut en être empêché, soit par suite de sa disparition par action de l'érosion ou par action directe de l'homme; soit par suite d'une dégradation de ses propriétés, surtout physiques ou physico-chimiques, due à son utilisation, en particulier comme système épurateur ou complexe de recyclage; soit par suite de son recouvrement par apport ou déversement d'éléments inertes.

Le rôle du sol dans le processus de recyclage des ressources naturelles est donc très complexe et présente divers aspects que nous allons étudier.

I. LE "RECYCLAGE" DU SOL LUI-MEME

Certaines activités humaines ont pour conséquence, directe ou indirecte, la disparition plus ou moins complète du sol. On peut tenter de la limiter, ou même, le cas échéant, de renouveler complètement le sol.

(A) Trop souvent l'activité agricole de l'homme provoque une *érosion* plus ou moins profonde et généralisée du sol. Il est fondamental de lutter contre. Les méthodes à appliquer sont bien connues. Les unes, comme l'établissement de murettes, de petits barrages en pierres sèches, ou la rectification des berges de cours d'eau peuvent nécessiter l'action d'organismes de travaux publics; les autres, comme la culture en bandes alternées, la réalisation de terrasses à large base, ou de haies vives, le reboisement, ou l'amélioration de l'état physique du sol, etc. correspondent à des opérations agricoles, le plussouvent de réalisation courante. Nous n'insisterons pas, ici, sur ce [illegible]

(B) Une autre série d'activités de l'homme peut faire disparaître le sol: creusement de *carrières* pour en retirer sables ou graviers calcaires, marnes, argiles ou terre à briques; extraction de charbons ou de minerais à ciel ouvert; ou, plus simplement, établissement de routes principalement celles en déblai ou remblai, d'aéroports, ou déversement d'éléments plus ou moins terreux aux abords de constructions: usines, habitations, etc.

Le fond des carrières, les terrils ou crassiers d'exploitations minières, les amas résultant des travaux de construction ou déblais dus à la réalisation des travaux publics, peuvent donner, en un temps plus ou moins prolongé, de nouveaux sols susceptibles de porter une végétation herbacée ou arborée ou des cultures. Ce renouvellement sera plus ou moins lent et efficace suivant le type de roche mise à nu, les méthodes utilisées, les précautions prises, mais aussi suivant les conditions écologiques du lieu envisagé, comme nous le verrons tout à l'heure.

II. LE SOL, SUPPORT D'ELEMENTS A RECYCLER

Le sol, en particulier grâce à sa perméabilité, aux propriétés de ses argiles et de sa matière organique, ainsi qu'à l'activité microbienne qui s'y développe, peut aider au recyclage de nombreux matériaux.

A Eléments liquides

Les *eaux résiduaires* de diverses industries, en particulier d'industries agricoles, telles que féculeries, sucreries, distilleries, usines de défibrage, etc., peuvent être recyclées par épandage sur le sol. Leur effet sur ce dernier dépend à la fois de la quantité d'eau déversée par unité de surface de sol et des propriétés physiques—perméabilité, porosité, etc.—de celui-ci, ainsi que des éléments en solution qui peuvent les modifier, mais, en même temps, de la masse de produits solides en suspension ainsi déposés.

Aussi ce problème des eaux résiduaires sera-t-il traité à la fois dans le cadre du recyclage des eaux dont il sera question tout à l'heure, et dans celui de l'étude du sol comme support d'éléments à recycler.

B Eléments solides

1. Parmi les éléments solides qui peuvent être recyclés sur ou dans le sol, il en est qui appartiennent à l'*écosystème*, naturel ou transformé par l'homme, dont le sol est un des éléments: feuilles, brindilles, branchages ou parties mortes du système racinaire. Soumis à l'activité des micro-organismes et de la faune du sol, ils se tranforment et évoluent; une partie des produits en résultant est évacuée dans l'atmosphère sous forme gazeuse, gaz carbonique surtout; une partie, constituée principalement par les éléments minéraux, éléments majeurs comme oligo-éléments, libérés au cours de cette destruction des corps organiques, peut être entrainée par l'eau qui percole ou rester dans les horizons supérieurs; une autre encore, transformée en corps organiques plus stables, acides humiques plus ou moins polymérisés, humine, reste dans le sol, devenant partie intégrante de l'humus de ce dernier.

Il s'agit là d'un phénomène d'une très grande importance que nous n'étudierons cependant

pas ici; nous l'avons abordé beaucoup plus en détail lors de la Conférence de 1973, à la Source-Orleans.

2. D'autres materiaux apportés dans, ou sur, le sol en majeure partie de nature organique, sont le résultat des *activités industrielles* ou *urbaines*. Il s'agit des ordures ménagères, plus ou moins triées—11 millions de tonnes par an en France—et de certains éléments, partiellement biodégradables, d'origine industrielle, qui peuvent participer à la constitution de gadoues plus ou moins transformées ou de composts. Certains ne sont que les produits solides déposés lors de l'épandage d'eaux résiduaires.

Ces éléments, au moins pour la plupart, peuvent se transformer, se simplifier au contact du sol; les processus de fermentation sont d'une importance primordiale dans tous ces phénomènes de recyclage.

Un cas assez particulier de ces résidus organiques est celui des lisiers accumulés en grandes masses—pour 5000 bovins, 130 tonnes d'éléments solides par jour—aux abords d'élevages industriels où les animaux se comptent par milliers.

Parmi tous ces résidus de l'activité industrielle ou urbaine de l'homme une part souvent importante est constituée d'objets non biotransformables. Leur apport sur le sol risque d'empêcher son utilisation ultérieure, et de dégrader plus ou moins profondément l'environnement, suivant le mode et l'importance de leur amoncellement. Leur débarras dans les carrières, dans les creux d'extractions minières à ciel ouvert permet de combler certains vides et de les faire servir de support à de nouveaux sols constitués artificiellement à leur surface.

Tous ces problèmes du recyclage des déchets solides et des boues d'eaux résiduaires vont être traités par Monsieur le Professeur S. Hénin, Président de l'Académie d'Agriculture.

III. LE SOL, COMPLEXE EPURATEUR DE POLLUANTS TOXIQUES

Dans l'agriculture moderne, des produits chimiques de diverses natures sont utilisés comme *pesticides* ou *herbicides*. Il en arrive une part souvent importante jusqu'au sol lui-même (elle peut atteindre 50% des produits appliqués). Il s'agit d'éléments tombés directement sur le sol; ou, au contraire de ceux qui, arrêtés d'abord par les parties aériennes de la végétation, y ont été ensuite intégrés, par suite du pluvio-lessivage ou lors de la décomposition des résidus végétaux qui en proviennent.

Le devenir de ces éléments est extrêmement divers. Il dépend des conditions écologiques du lieu—des pluies qui y tombent et de la température qui y règne—des propriétés du sol—en particulier de sa perméabilité, de sa teneur en argile et du type de celle-ci, de son pouvoir absorbant, de son activité microbienne; et surtout de la nature des constituants minéraux ou organiques du produit toxique utilisé.

Si le sol est suffisamment filtrant et le milieu percolatif, le produit peut être entrainé par les eaux de pluies, s'il est assez soluble, tel un pesticide comme le parathion, ou un herbicide tel l'atrazine; ils peuvent, d'ailleurs, ensuite contaminer la nappe phréatique, s'ils ne sout pas retenus ou décomposés au cours de leur trajet à travers le sol. D'autres sont facilement dégradés par voie bactérienne; dans le cas d'autres encore, certaines molécules organiques ou certains ions minéraux, cations en particulier, peuvent être absorbés par le sol, ce processus dépendant à la fois de la nature même de ces corps et des propriétés du complexe absorbant du sol, de son pH, etc.

Au total, certains de ces pesticides et herbicides, tels

DDT, se maintiennent longtemps dans la plupart des sols; d'autres au contraire, tels les organophosphorés sont beaucoup moins persistants.

Le problème de l'évolution de ces corps dans le sol dans les différents milieux écologiques est d'autant plus important qu'ils peuvent avoir une influence parfois bénéfique, souvent néfaste, sur l'activité microbienne qui s'y développe. Des recherches approfondie sont encore indispensables pour connaître et comprendre tous les aspects et toutes les conséquences de cette évolution.

En résumé, le sol reste une des ressources naturelles les plus importantes pour l'homme; son rôle dans le processus de recyclage est, à bien des points de vue, fondamental. Il est aussi très divers et très complexe . . . et nous sommes loin encore d'en connaître tous les aspects, tous les détails.

SUMMARY

It was foreseen to study "the effects of recycling in Agriculture". Such a subject is a too large one; it would need a total colloquium by itself. The communications and discussions have dealt with one natural resource: the soil.

The soil is an essential natural resource, not only by itself and because it bears the vegetation through which we can utilize solar energy, but also because it can be a means to recycle quite a number of wastes.

Some of these wastes are brought to the soil as a solution or a suspension in water. The soil, then, plays as a filter or as a medium for bio- or photo-destruction of these materials. In such a case we have to prevent the soil being degraded through its physical properties or chemical or biological conditions. Other wastes are brought to the soil in a solid form (domestic dirt, filth). Such a problem has been presented by Professor S. Hénin, chairman of the French Academy of Agriculture. A very interesting comment has also been made by Doctor Walker from Beltsville (U.S.A.) on the optimum agricultural use of these filth.

A special problem is due to the use of herbicides and pesticides, which is strong and definitely necessary in a modern and effective agriculture. This problem has been presented by Doctor Viel from INRA (France) in the place of Doctor Greenland who unhappily was unable to attend the conference. A large part (perhaps up to 50%) of these products returns to the soil. A number of them can there be biodegraded or are leached to the deep subsoil. Others can accumulate on the surface or in the ground water tables, and they can become noxious. In such a case they are not to be used.

Another side of the problem is the recycling of the soil itself. This case may happen either after destruction of part of the soil or after taking the whole soil and the material underneath away: open air quarries, bottoms and heaps of mining debris, places along roads, buildings, strongly eroded areas, etc.

Through natural effects, a new soil can develop in a few years to quite a number of centuries, depending upon the type of material and the local ecological conditions. Time may be greatly decreased through mechanical work of the soil, or by developing certain crops, grasses, bushes, and trees. The case of Al, Co, Cr, Fe, Ni, open air ore mining, as it so often happens in tropical countries, is one of the most difficult.

As a conclusion we must remember that soil is an essential natural resource, necessary for the life of manhood and its quality. We need to prevent its degradation, its destruction and, as often as possible, we need to recycle it. We also have to get a better knowledge of newly usable soils and the covered areas; as well of their evolution and their characteristics,

so as to make a better use of these, while preserving or even improving their level of fertility and productivity.

LA FORMATION DES NOUVEAUX SOLS SUR LES FONDS ET DÉBLAIS DE CARRIÈRES OU D'EXTRACTION MINIÈRE A CIEL OUVERT ET SUR LES DÉBLAIS ET REMBLAIS DE TRAVAUX PUBLICS ET DE CONSTRUCTIONS

G. AUBERT

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I

(A) Chaque année des surfaces importantes de sols disparaissent, par suite du creusement de nouvelles carrières et de zones d'extraction à ciel ouvert de minerais, charbons ou autres, de la mise en place de terrils ou crassiers de mines, ou par suite du raclage des terres au long de routes, autoroutes, aéroports, ainsi que, sur les emplacements ou aux alentours de nouvelles constructions industrielles ou d'habitation.

(B) Ce processus est d'autant plus dommageable que les superficies de sols ainsi enlevées à leur rôle fondamental, sur lequel nous avons insisté au début de ces débats, augmentent sans cesse, du fait de l'extension considérable des surfaces, précédemment à utilisation agricole, et maintenant urbanisées, industrialisées ou transformées par les grands travaux publics. Par ailleurs, par suite du développement de la tendance actuelle à l'utilisation de minerais à faible teneur, les volumes de matériaux extraits, souvent à profondeur assez limitée, sont de plus en plus importants et les surfaces de sols ainsi dégradées aussi. Enfin, dans beaucoup de cas, comme par exemple en Nouvelle-Calédonie, dans l'exploitation du nickel, les déblais accumulés au flanc de montagnes ou de collines aux fortes pentes peuvent être entrainés par l'érosion et venir recouvrir d'une couche peu fertile des sols de vallée souvent beaucoup plus productifs. Or, dans les conditions mondiales actuelles, il importe de ne pas laisser diminuer les sols utilisés pour la production d'aliments pour l'humanité ou le maintien des conditions de vie qui lui sont indispensables.

(C) L'évolution de ces amas de matériaux, des roches mises à nu ou des sols profondément décapés se produit naturellement, mais le temps nécessaire pour que soit de nouveau constitué un sol fertile est très variable, souvent très long. Il ne faut que quelques années dans la région parisienne pour qu'un fond de carrière de terre à briques, limon plus ou moins sableux ou argileux suivant les cas, puisse porter des cultures; dans l'ouest de l'Algérie, sous un climat de type méditerranéen semi-aride, en quatre ou cinq ans, un [illegible] calcaire très friable, décapé par la mise en place de [illegible] [illegible]tion, [illegible] naissance à un nouveau sol; par contre, dans l'ouest de [illegible]

plus élevée, ce n'est qu'au bout de plus d'un siècle que les crassiers de schistes ardoisiers se recouvrent d'une végétation arborée.

II

Pour qu'un sol puisse renaître sur ces roches mises ainsi à jour par l'homme, il faut que puissent se réaliser l'hydrolyse des minéraux qui permettra la formation d'éléments argileux essentiels pour le développement du sol, souvent la dissolution ou l'entraînement de certains éléments, sels, constituants métalliques, calcaire, etc., et s'installer la vie microbienne, puis une végétation, si réduite soit-elle, origine toutes deux de la matière organique du sol.

De tels phénomènes sont lents à se produire; il est donc indispensable que soit assurée, pendant un certain temps, la stabilité du matériau. Aussi leur réalisation dépend-elle non seulement de la nature de celui-ci, mais aussi de sa position topographique ainsi que des conditions écologiques du lieu. Pratiquement, ils ne peuvent intervenir, ou seulement sur des temps très longs, en zone aride, en zone froide, en région de montagne aux fortes pentes ou sur des matériaux très peu altérables.

Parmi les caractéristiques du matériau à transformer, certaines, fréquentes dans le cas étudié, peuvent être particulièrement défavorables. Sur le plan physique, il s'agit très souvent d'éléments rocheux, qui ne peuvent donner de sols et porter de végétation qu'au fur et à mesure qu'ils se morcellent, se désagrègent et se transforment en constituants assez fins. Dépourvus de minéraux argileux et de matière organique, ils ne possèdent en général aucune structure et ne peuvent retenir que de faibles quantités d'eau, propriété essentielle pour le développement des plantes.

Sur le plan chimique, ces matériaux présentent souvent des déséquilibres, comme le grand excès de magnésium et la grande pauvreté en calcium des déblais des mines de nickel, ou une grande richesse en un produit facilement toxique pour la végétation: manganèse, aluminium, nickel, cobalt, suivant le cas, au Gabon, en Nigeria, en Nouvelle-Calédonie, etc., ou en sels solubles comme sur les boues résiduaires des mines, de sodium ou de potassium dans l'Est de la France, par exemple. Enfin, la vie microbienne, au départ, y est nulle ou très faible et doit, peu à peu, s'y développer.

On peut laisser le sol se refaire naturellement. Après un certain temps de désagrégation et d'altération des matériaux, après un entraînement suffisant par les pluies, des éléments en excès, une pédogenèse initiale, visible, s'installe. Mousses et lichens apparaissent, suivis d'herbes et d'éléments semi-ligneux, enfin de jeunes arbres, variables suivant les régions.

L'homme peut aussi accélérer le phénomène par des apports d'engrais, souvent difficiles d'ailleurs à adapter aux conditions locales, de matière organique dont l'efficacité est généralement très grande et par le travail du sol. Ce dernier permet une plus rapide décomposition du matériau, une meilleure pénétration de l'activité biologique et une action plus profonde des agents atmosphériques. Il est particulièrement indispensable dans la récupération des terres polluées par les résidus pétroliers, comme en U.R.S.S., autour de Bakou, par exemple.

Enfin, il est également possible d'organiser cette formation du sol en réservant la terre des horizons superficiels ou en en rapportant d'ailleurs, pour recouvrir les éléments mis à nus ou les déblais; puis en cultivant, suivant les méthodes les plus élaborées, des herbes telles que graminées ou cypéracées, pour refaire la structure du sol, et des arbustes et arbres, tels que pins, robiniers, etc., pour permettre une plus profonde transformation et une stabilisation plus efficace du matériau, comme c'est actuellement en essai en Nouvelle

Calédonie, sur des déblais de mines de nickel, comme c'est réalisé aux Etats-Unis, en U.R.S.S. (mines de manganèse) et dans beaucoup d'autres pays.

Chaque cas doit être étudié en fonction des conditions topographiques, pétrographiques et écologiques. Les méthodes à appliquer doivent être prévues avant que ne soit entreprise la destruction du sol actuel.

LE POUVOIR EPURATEUR DES SOLS

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Le sol est utilisé à diverses fins par ceux qui produisent des déchets.

Dans cet exposé nécessairement bref, je ne parlerai pas de l'utilisation du sol comme dépotoir, c'est-à-dire du lieu où viennent s'accumuler les carcasses de vieilles voitures ou les résidus divers. Je ne parlerai pas non plus des surfaces utilisées comme stockage pour les résidus urbains avec essai de constitution de nouveaux sols, ce qui pose un problème très particulier.

Le cas le plus fréquent qu'on puisse évoquer est l'épandage des résidus urbains plus ou moins préparés ou triés sur des terres agricoles. La méthode est classique; les terrains maraîchers qui entourent les grandes villes ont été enrichis de cette façon, et même la grande culture péri-urbaine a largement utilisé ces substances. En général, les résultats ont été bénéfiques; il faut signaler, parmi les inconvénients résultant de l'emploi des gadoues non triées, l'accumulation des fragments de verre et l'élévation du pH du sol. Toutefois, à ma connaissance, les accidents résultant de cette situation n'ont pas été fréquents.

Mais la nature des gadoues a évolué considérablement avec le remplacement du bois, puis du charbon, par d'autres combustibles, et l'utilisation de plus en plus systématique des plastiques. Les risques d'élévation du pH qui étaient liés aux cendres sont beaucoup moins importants; par contre, le salissement des terres par le plastique constitue un problème. Toutefois, les bonnes gadoues ont été débarrassées par des tris préalables de leurs éléments métalliques, du verre, et des plus gros fragments de matière plastique. Actuellement, les problèmes qui peuvent encore se poser concernent non seulement les gadoues, mais les boues de stations d'épuration qui renferment des oligo-éléments d'une part, et des pesticides, dont l'usage interdit en agriculture peut être maintenu pour les habitations, sans compter les produits organiques ou minéraux divers qui peuvent être plus ou moins toxiques. A titre d'exemple, voici quelques teneurs de gadoues en oligo-éléments. (Table 1).

On constate que les gadoues ont des teneurs en éléments majeurs comparables à celles des fumiers. Ce fait justifie leur emploi comme engrais. Mais leur teneur en oligo-éléments est beaucoup plus élevée, il faut donc tenir compte de ce fait qui pourrait être à l'origine d'accidents. A ces données, on devrait ajouter la teneur en éléments toxiques, Pb, Hg, Cd, qui peuvent être présents dans ces substances.

Le problème des produits organiques est malheureusement beaucoup moins connu; il va faire l'objet de recherches dans le cadre d'un appel d'offres lancé par les services de l'Environnement.

Au fond, le problème des gadoues peut se résoudre par trois techniques: la combustion,

TABLE 1. Composition comparée de quelques gadoues, des fumiers et des pailles en éléments majeurs et en oligo-éléments*

Composition en éléments majeurs	P_2O_5	K_2O	CaO
Compost d'hiver	0,41	0,48	3,52
Compost d'été	0,61	0,35	3,22
Fumiers bien décomposés	0,30	0,44	2,15
Fumiers peu décomposés	0,19	0,56	1,32
Paille	0,12	0,15	—

	Pour cent du total			p.p.m. du total			
Moyennes	Fe	Na	Mg	Mn	Cu	B	Co
Composts d'hiver	1,44	0,24	0,27	263	326	26	4
Composts d'été	0,98	0,25	0,18	205	266	17	4
Fumiers	0,06	0,08	0,08	74	6	6	0,4
Pailles	0,04	0,01	0,04	18	2	2	0,09

le stockage en grandes quantités sur une petite surface et l'épandage. Jusqu'à présent le coût de l'opération est tel qu'en ce qui concerne l'épandage il n'y a pas trop à craindre des accidents, sauf, encore une fois, ceux qui seraient liés à des produits très toxiques, de nature minérale ou organique. Mais le cas le plus difficile concerne l'épandage des boues plus ou moins concentrées provenant généralement d'industries agricoles. Une première difficulté tient à leur concentration, extrêmement variable au cours de la saison de production. Une seconde est due à ce que ces effluents, selon la nature des industries, peuvent être produits soit pendant une partie de l'année (cas des sucreries et des féculeries) soit en toute saison comme dans les laiteries. Il faut ajouter à cette série le cas des lisiers. Nous ne pouvons pas discuter ici du problème du stockage plus ou moins prolongé de ces effluents, malgré les difficultés qu'ils soulèvent: risque de pollution de l'air (odeurs) ou des nappes (étanchéité des bassins de stockage).

Le pouvoir épurateur des sols est utilisé depuis longtemps déjà pour purifier les eaux d'égout des grandes villes. Les terrains d'Achères, par exemple, servent depuis un siècle à cette fonction. Pour traiter ce problème, j'utiliserai largement les informations présentées dans un numéro récent des Annales Agronomiques.†

Le pouvoir épurateur des sols est lié aux fonctions suivantes:

1°) filtration des éléments grossiers et colloïdaux (y compris les micro-organismes);

2°) rétention des cations et de certains anions.

Ces propriétés sont liées à la constitution du sol, mais elles peuvent être modifiées par son fonctionnement en tant que filtre. C'est ainsi que les éléments minéraux fins peuvent colmater le terrain qui, de ce fait, perdra son pouvoir filtrant. Mais le sodium absorbé par la fraction colloïdale peut également, en modifiant l'état de floculation des colloïdes du sol, parfois jusqu'à la dispersion, rendre le milieu imperméable.

Les colloïdes organiques peuvent aussi colmater le sol et lui faire perdre son pouvoir

* Bulletin de l'Association Française pour l'Etude du Sol n° 9, Septembre 1960.

† *Annales Agronomiques* n° spécial "Pollution", vol. 25, n° 2.3, 1974.

filtrant, mais de ce point de vue il faut distinguer les produits fermentescibles et ceux qui le sont peu. Le cas des produits peu ou pas fermentescibles se ramène au colmatage par des éléments minéraux fins. Nous verrons comment remédier à cet accident. Un fait doit être noté; ils sont très inégalement fixés par le sol, si bien qu'une partie peut être directement entraînée dans les nappes sous l'influence d'arrosages intenses et continus. Les éléments fermentescibles auront tendance à être détruits par l'activité microbienne du sol. Encore faut-il que les masses apportées en un temps donné ne provoquent pas une modification de l'atmosphère du sol qui rende les fermentations anaérobies. En effet, ces dernières sont moins actives que les fermentations aérobies, mais leur inconvénient le plus grave est qu'au lieu que la matière organique soit pratiquement minéralisée par les fermentations, il se produit, avant d'arriver à ce stade ultime, des composés intermédiaires, souvent acides et généralement doués d'un pouvoir complexant. Tous les cations présentant plusieurs états d'oxydation peuvent alors passer en solution, d'autant plus que, étant complexés, ils ne seront pas réabsorbés par les colloïdes du sol. Ils peuvent être alors entraînés vers la nappe ou dans les eaux des canaux collecteurs.

On peut dire que dans ces conditions réductrices, il est extrêmement difficile de prévoir le comportement des éléments, quelle que soit leur nature. Ainsi, lorsque, soit en raison d'apport d'un excès d'éléments ou d'eau, se créent dans un champ d'épandage des conditions réductrices, non seulement la vitesse d'infiltration diminue et peut même s'annuler, mais par surcroît le filtre n'arrête plus les éléments.

Le pouvoir épurateur du sol peut se mesurer en quantité d'éléments susceptibles d'être oxydés pour un régime d'alimentation hydrique donné. Bien qu'en principe ce pouvoir épurateur soit très lié à la texture, il varie de 500 à 2000 kg de DCO Ha par jour. Rappelons que le DCO est la quantité d'oxygène nécessaire pour oxyder la matière organique contenue dans l'effluent. Cette façon d'apprécier la situation peut paraître sommaire, mais comme la nature des produits organiques renfermés dans les eaux usées est extrêmement variable, il vaut mieux prendre comme commune mesure la quantité d'O_2 nécessaire à les oxyder.

Il faut également considérer le rendement de l'opération: à mesure qu'augmente la quantité de matière organique, le pourcentage détruit va en diminuant et les risques de pollution des nappes s'accroît. Il faut tenir compte de la quantité d'eau apportée par l'effluent et de la perméabilité du sol. Une dose relativement faible de matière organique apportée dans un grand volume d'eau maintenant le sol au voisinage de la saturation sera moins bien épurée que des quantités plus importantes mais moins diluées. Par exemple, pour les effluents de fosses septiques renfermant une dose de 200 kg de DCO/jour/Ha et un épandage presque continu, le rendement est de 75%. Pour une conserverie de maïs, avec une DCO de 1,8 g/l et un épandage de 360 kg/jour, la baisse de DCO a atteint 87%.

Les sols colmatés par des éléments colloïdaux peuvent être récupérés en enfouissant la couche superficielle par le travail du sol, en installant des cultures d'herbe sur le milieu et en amenant une dessication plus ou moins poussée du terrain. D'ailleurs, les effluents très chargés en matière solide fine sont souvent amenés dans les champs dans des rigoles et, après colmatage, un labour permet de mélanger les sédiments fins à la masse de terre.

Une autre cause de colmatage est due au sodium. Les articles de Gras et Morizot, Graffin, Germond et Catroux dans des Annales Agronomiques, cités en référence insistent sur la teneur élevée en Na des eaux d'épandage. Cet élément est utilisé dans les adoucisseurs d'eau employés dans les industries. On sait que les risques d'accumulation de Na deviennent sérieux quand le SAR

(sodium absorption ratio $\frac{Na^+}{\sqrt{(Ca+Mg)/2}}$ (s.o.r.)

est supérieur à 2. Or, au cours des enquêtes, cette valeur était très souvent dépas de beaucoup, dans les eaux d'épandage. La parade consiste à limiter leur concer des recyclages dans les usines, mais aussi à utiliser les sols renfermant du CO_3C tenir une végétation prairiale dont les racines améliorent ou protègent la struct

Nous avons vu que le sol pouvait également retenir une partie des cations pr les eaux, en particulier K. Cette fixation s'accompagne d'une perte de Ca^{++}. Pour trop abondants, le milieu finirait par être saturé et les éléments ne seraient pl Il est donc essentiel que les terrains d'épandage soient cultivés et qu'on y p végétaux ayant de très grandes exigences en eléments nutritifs. Il y a d'ailleurs un à établir entre les doses apportées par les eaux usées, la surface irrigable et les ex Voici de ce point de vue les besoins de quelques récoltes:

Culture	Rendement T. Ha	N	P_2O_5	K_2O
Fétuque élevée	104 en vert (18,6 en mat. sèche)	536	61	679
Betterave à sucre	45	70	24	98
Pommes de terre de féculerie	35	82	31	188

Ces différentes considérations laissent prévoir que même si les épandages an relativement limités, il peut y avoir entraînement quand les apports instan surabondants. C'est ainsi que G. Lefèvre, étudiant à l'aide de lysimètre les résultat d'eaux de féculerie, constate qu'en 1970-71, pour des apports de 39T/Ha de DC 52 kg drainés, alors qu'en 1971-72, pour 23 T/Ha il y a eau 454 kg drainés. La cau différence réside dans le fait que les épandages de 71-72 ont été effectués sur humides où l'eau apportée a donc tendance à drainer, alors qu'en 70 le drai relativement faible.

On peut donc dire en conclusion que le sol est un excellent système épurateur à qu'on n'en abuse pas. Cela veut dire que les doses apportées doivent être ad propriétés du sol, tant en ce qui concerne la vitesse d'infiltration que son pouvoir pour les matières organiques qui traduit la vitesse de circulation des gaz dans le la porosité. C'est-à-dire que les industriels doivent prévoir un réseau de dist la dimension du volume de leurs effluents. Ils pourront d'ailleurs réduire cel la mesure où, grâce à des traitements préalables tels que les décantations, ils la charge de leurs eaux.

Mais l'état des terres et l'efficacité du sol en tant que filtre ne joueront leur plei s'il porte une végétation capable d'utiliser l'eau et surtout les éléments fertilisants De ce point de vue, l'agriculteur est largement bénéficiaire des épandages; non les cultures de la région d'Achères en sont un exemple, mais récemment encor servait des augmentations de rendement de 50 et de 100% sous l'influence des ép

Sans vouloir dire que ces problèmes soient complètement résolus, l'expérienc qu'on peut, dans une large mesure, éviter les pollutions grâce à un épandage jud les terrains agricoles dont la condition se trouve améliorée. Cette circonstance f

coût de ces opérations peut se trouver sinon bénéficiaire, du moins largement amorti grâce aux bénéfices que l'on peut en tirer. Bien sûr, les pollueurs, c'est-à-dire les villes et les industries, doivent supporter une part importante des charges qui découlent de ces opérations. Il n'est pas exclus toutefois qu'après une bonne concertation et des plans d'utilisation judicieusement aménagés, l'agriculture ne puisse supporter aussi une partie du coût de ces opérations, étant donné le bénéfice qu'elle en tire.

S'il m'a paru utile de conclure sur ces aperçus économiques, c'est qu'il semble qu'actuellement les partenaires se renvoient plus ou moins les responsabilités, ce qui est certainement un obstacle à l'adoption de solutions qui devraient être bénéfiques pour tous.

SUMMARY

Following an analysis of the factors determining the purifying capacity of soils, the author emphasizes the fact that this capacity varies according to the substances applied.

He also stresses the fact that this capacity will not work nor have a lasting effect if the larger part of the elements put into the crop have not been absorbed by the harvest.

When the residues contain toxic elements, they must be utilized on plants, non-edible for humans, such as trees, or destroyed by fire.

DISCUSSION

DYKE: I don't want to tread on the toes of the experts but I have found in my own work that there is marked disagreement as to whether or not there is damage done to the soil as a result of applying sludges and introducing trace metals that are damaging in the long term. There are very indistinct, opposing views on this amongst the experts. Speaking as a layman, I would like—and I'm quite sure many of us who have been called upon to apply technology—this matter settled, if it is at all possible (and I very much doubt if it is because the experts are finding it very difficult to agree amongst themselves here). In my own experience over 15 years I have yet to find a case of any damage to livestock. I'm not too familiar with the extended food chain and refer to damage to livestock as a result of the application of either sewage or farm sludges direct to the land—I'm not saying there hasn't been the odd case of staggers and that sort of thing—but this could arise from any sources. It is not necessarily the metals content of farm sludges is excessive as a result of what we call the cubicle system of housing, giving rise to a greater accumulation of sludges. The factor in applying sludge to land from a technical point of view rests, I believe, in the method of application. My experience is that if you apply it by the spray or surface technique, then you've got to be reasonably careful of how you go about it. You can here get surface soil clogging and immediate contamination of the plant growth foliage. There is also the seasonal factor which is very difficult to accommodate. In the summer growing season, growing crops cannot be disturbed and in the winter you have a lower ambient average temperature inhibiting bacterial (aerobic) activity, high water content in the soil run off to steam and difficulties in that direction. Ideally, I think, the sludge should go under and I think if it goes under, say 8–9 inches, you'll get a satisfactory break up and the metals will not cause you a great deal of trouble. Again, you're up against the problem: when do you get it to the land to get it under? In the summer you've got plant growth, in the winter you've got wet land. It's all a question of how you plan your routine.

JOY: We have been asked to do reclamation on about 450 acres of old colliery tips which also include some mining wastes. One of the experiments we hope to carry out based on the U.S. Bureau of Mines' work is on the effect of putting compost and sewage sludge at different levels beneath the surface when spreading spoil heaps for reclamation. Particularly, the Bureau found that there was a large change in the amount of toxic ions transported to the plant roots which varied according to the level of the sludge. I would like to ask whether the U.S. Bureau of Mines' representatives have any further knowledge other than that which has so far appeared in the literature. The most important point concerns the depth at which one places these sludges under the subsoil.

ROSS: We have large quantities of pulverized fuel ash to dispose of, and I have been concerned with this. With the addition of only a few centimetres of soil, of sewage sludge, or of some waste from poultry houses, excellent crops can be grown, and animals have been successfully grazed on such fields. The biggest problem with new ash is boron, which takes 2 or 3 years to wash down below rooting level. In my own garden I had 80 cubic metres of ash which set to a rock. To plant shrubs I chipped out holes about 1 metre in diameter and filled them with soil. All shrubs are growing well, but I hoped that weeds would not grow between them. Unfortunately the weeds grow very well also.

HIGBIE: I'm with the Bureau of Mines and I think I should provide an answer to the question that Dr. Joy addressed to us. Unfortunately the answer is we have no further information to report at the moment other than that which has been previously published. The research does take time and emphasis on it has been minimized at our Salt Lake City Metallurgy Research Center because of other higher priority investigations—they are continuing to study the subject on a small scale.

WATER RESOURCES AND CHANGING TECHNOLOGY

JOSEPH T. CALLAHAN

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As we meet to discuss water as part of a plan of action for mankind in a world of technological change, increasing population, and water demand, let us keep in mind that the world water supply has essentially neither increased nor decreased since the earth atmosphere was formed millions of years ago. While water use continues to escalate in response to an expanding world population, which is expected to double in the next 35 years, the total amount of available water remains the same.

The uneven distribution of water resources has long been a problem. Droughts experienced in this and recent decades have prompted increases in water recycling and brought about a more general awareness of the benefits of reuse. Some major cities in the world already withdraw river water that may contain as much as 50% sewage effluent. Numerous reports attest to successful spray irrigation of sewage effluents that stimulate crop production, and land spreading techniques have been used successfully to dispose of wastes and, at the same time, to reclaim or upgrade poor and despoiled areas.

Artificial recharge of aquifer systems for water-supply storage and as buffers against salt-water intrusion is becoming more common. Thus, it would seem that there is no longer the question of whether water should be recycled, but rather how, where, and when it should be done.

During these meetings we have heard of impending shortages of energy and minerals that may tend to limit the advancement or development of mankind. Of all of these shortages, none will be more important or more limiting than water. And, basically, we are limited economically to the fresh water that falls on the continents and returns overland and underground to the seas.

For the United States, we can project water shortages in half of the country by the year 2000, based on present usage and technology. Changes in usage and improvement in technology might lessen the projected shortages, but with the population increases there still will be shortages and probably a deteriorating quality of life.

The deteriorating quality of life that the world faces is caused by far more than population pressure. It is caused also by increased per capita demand, faulty technology, and mismanagement. With respect to water resources, one of the most common results of mismanagement has been contamination. Water, whether in a river or underground, is susceptible to contamination from both man and nature. As population increases, the susceptibility for contamination increases. As land becomes more densely populated, it becomes increasingly difficult to prevent contamination. Exclusive of man, the protection of water

is dependent on the interrelated factors of climate, vegetation, soil development, and geologic and topographic conditions.

It is man's activities, primarily, with which we are concerned here. How do water and agriculture fit into a world of development and recycling? Will people accept reclaimed water and, if so, with what limitations?

Water will be in greater demand. More will be required for irrigation agriculture, and consumptive use will increase. Return flows to rivers or to underground reservoirs will carry increased loads of fertilizers, insecticides, and herbicides.

In the seventeen semi-arid western States of the United States, water withdrawn already is 90% of the dependable supply. About 20% of that withdrawn is lost to consumptive use. Water use is increasing about 3% per year. With the advent of oil-shale development and surface mining and the water uses attendant to production and land reclamation, consumptive use is scheduled to increase dramatically. As a possible trade-off in water use, agriculture may have to return from the semi-arid west to the humid southeastern United States in order to lessen the impact of consumptive use and increased salinity of western rivers.

In our session on water and agriculture, we have heard of the experiences gained through studies and experiments. In Pennsylvania, U.S.A., animal wastes have been recycled on to the land to produce animal feed and trees. The farmed study area is in a temperate climate where annual precipitation is about 1000 mm, and they have successfully sprayed more than an additional 1000 mm of liquid wastes. Feed crops and trees have removed essentially all the nutrients, and the soil aided in the removal of bacteria and viruses. A monitoring system indicates that the water leaving the farmsite is of as good quality, including chemical, biological, and aesthetical characteristics, as the water in nearby streams. In other words, by recycling the wastes, the entire environmental setting has been enhanced, and fiscal profit has been earned by a savings in fertilizers used, and feed crops and trees produced.

The recycling of municipal wastes can and will be beneficial not only to the world of agriculture where much can be used, but to the cities which will be aided in solving their problems of disposal, and to the downstream users of the streams who will not have to suffer the problems of heavily polluted rivers.

We heard the results of several years' experiments on the recycling of municipal sewage sludge in the outskirts of Washington, D.C. by the U.S. Department of Agriculture's Research Service. Questions that they are trying to answer include—whether the methods are economically and technically feasible; will the methods be politically and socially acceptable; what are the benefits and the hazards to soils and crops, animals and man?

In a completely different environment, investigations of the hydrologic aspects of recycling water are being made in permeable carbonate rock of relatively warm and humid Florida, U.S.A. The region experiences an annual cycle of drought and water surplus. With the increased demand for water for agriculture, industry, and public supply, each succeeding drought causes economic hardship, and it is estimated that in the next 10 years, Florida may be the greatest user of recycled water. The recycling methods so far used include spray irrigation of waste water on green belts and golf courses, storage of storm runoff underground in permeable saline aquifers, injection of effluents from secondary or modified advanced waste-treatment plants into deep saline water aquifers, and the use of digested sludge in the production of grass sods.

A U.S. food processor has deliberately located food processing plants in rural areas where they have utilized the local environment to treat the waste waters of the processing plants. In one system, water is sprayed on sandy soil, where the quality is improved by

filtration and plant production, and at another by utilization of an overland-flow system, where the soil is too impervious to permit high infiltration rates. Both systems have been successful in removing more than 98% of the BOD for a period of several years.

Studies have been made of a region where more than 2.5 million persons depend entirely on ground water for supply and where, until recent years, the water was almost completely recycled through septic tanks and sewage-treatment plants back to the underground. This resulted in deterioration of ground-water quality, with a significant increase in nitrate and other dissolved solids. Because of the limited supply of water, waste-water reclamation and ground-water recharge experiments have been conducted to determine the technical limits. However, the data indicate that in the recycling of water, the increase of total dissolved solids is inevitable.

The city of Chicago, situated on the shores of the Great Lakes, has the problem of disposing of an ever-increasing volume of municipal wastes of several million persons. They have been recycling digested sewage sludge on farm lands and abandoned strip coal mines with good results. Data indicate, that among other advantages to the methods, viruses are not likely to survive the heated anaerobic digestor environment and be transferred to the disposal site. The studies also indicate that the land has a limited capacity to accept digested sludge, and that if the limitations are exceeded, some of the more soluble heavy metal constituents may adversely affect the growth of crops or result in the accumulation of some chemical elements in crop tissue at concentration levels that might pose a threat to animal or human health. The use of sludge on abandoned strip mines has improved the agronomic properties of the soil and helped neutralize the acidity of the overland runoff from the mines.

A study of a heavily industrialized valley in Korea has shown that the infiltration of industrial wastes to the sands and gravels underlying the valley has permanently altered the chemical quality of the streamflow that drains the area. The low flow of the stream, derived from ground water, has a pH and dissolved solids significantly altered from that of nearby streams draining agricultural valleys.

The data being accumulated in present and recent studies indicate that the recycling of wastes and wastewaters is technically and economically feasible within limitations. We are also re-learning what past civilizations have learned; that wastes can be recycled.

The public must be educated to accept the concept of using reclaimed water and other reclaimed materials. A study of public attitudes* made in California indicated that more than 50% of the respondents to the survey recommended against using reclaimed water for purposes involving personal contact. The study also showed that most persons favored treatment and reuse of wastewaters but for purposes not involving significant personal contact.

In conclusion, we have the following suggestions for your consideration:

In Developed Countries, for Planning and Conservation

The increasing rate of the total per capita water usage in developed countries is beginning to pose a serious threat to this limited resource. Developed countries should implement conservation of this resource by more effective management and utilization of water for agriculture, industry, and recreation, because the direct consumptive needs of man are minimal and fixed.

* Brovold, William H. and Ongerth, Henry J., Public use and evaluation of reclaimed water. *J. AWWA*, 1972.

In Developing Countries, for Planning and Conservation

Developing countries should incorporate in all their long-term planning a sound program of water management and conservation to ensure against diminishing or diminished supplies that would result from overuse, improper development, or contamination.

Effects of Recycling

The session on effects of recycling upon water and agriculture indicated that:

1. Recycling, properly controlled, can aid in:
   (a) reducing the impact of wastes and waste disposal on the hydrologic environment;
   (b) having a positive benefit on agriculture and potential benefits to industrial and other uses;
   (c) improving effective use of water resources through improved water management.
2. Recycling, where technically feasible, may be implemented by various methods, among which are:
   (a) land spreading of treated effluent, sludge, and animal wastes;
   (b) subsurface storage of effluents and storm runoff for treatment and reuse.
3. Prior to implementation of recycling:
   (a) methods to be employed must be carefully assessed;
   (b) assessment must encompass broad aspects and details of the hydrologic setting;
   (c) consideration must be given to use of simulation and predictive techniques based on the current status of computer technology for modeling flow systems and chemical and biochemical reactions.
4. Once implemented:
   (a) recycling must be adequately monitored and data continually evaluated in order to protect water resources;
   (b) care must be exercised in all types of recycling to ensure that contamination of water resources and the biologically active soil zone is kept to a minimum.
5. Recycling, even under the most favorable conditions, can result in some degradation of the hydrologic environment.
6. Emphasis needs to be continued upon improving the ability to quantitatively simulate and predict the impact of recycling.
7. In general, adequate technology exists to permit improved management and use of water resources through controlled recycling without unduly harming the hydrologic environment.

DISCUSSION

KEILLING: C'est avec un vif intérêt que j'ai écouté les remarquables exposés de nos collègues nord-américains, au sujet de la raréfaction de nos ressources et des aménagements qu'impose la situation présente. Cependant, je crois devoir ajouter à leurs propos une indication complémentaire basée sur une situation que les Européens ont connue depuis 1939 jusqu'au rétablissement des échanges internationaux (1946? par exemple) mais que le nouveau continent n'a jamais connue et, par conséquent, jamais étudiée.

Dans l'Europe en guerre, la pénurie avait remplacé l'abondance pour deux raisons: l'une maritime: arrêt des importations par la voie des mers, l'autre "terrestre": les milliers d'hommes arrachés aux productions pour devenir destructeurs et consommateurs!

A cette époque de pénurie, il n'y avait plus guère de résidus non recyclés et l'on peut dire que, à cet égard tout au moins, certaines pollutions reculèrent!

Mais d'un autre point de vue, l'on vit apparaître, ou réapparaître, pour satisfaire les besoins fondamentaux des nations, des opérations de retour à des procédures disparues, qu'un récent progrès technique avait éliminées: le charbon de bois ou le bois alimentant les moteurs à explosion, le tracteur hippomobile ressuscitait, les "ersatz" de tous genres étaient remis en honneur: il y eut à cette époque, chez tous les belligérants européens assaut d'ingéniosité imposée par le désir de survie des individus comme des nations.

Au printemps 1945, avant la fin des hostilités en Allemagne, W. Churchill, s'interrogeant sur le destin du peuple vaincu, posait la question à ses services: "*quel est exactement l'état de leurs labours?*" Voilà le problème essentiel qui domine toute notre réunion "quel est exactement l'état de *nos* labours?" entendons par là la capacité productive de nos sols?

Problème essentiel et éternel et cependant mal perçu par l'opinion publique, voire par les dirigeants politiques; certes il ressort des préoccupations à long terme et l'évolution des sols n'est pas spectaculaire; il n'est pas, dans ce domaine, de catastrophes dramatiques qui ébranlent brutalement l'humanité... mais ceci n'est pas une raison pour escamoter le problème!

Quand on tente de survoler ce grave problème, on est ramené à l'évolution du rôle de l'humus, matière organique des sols, legs des vies antérieures dont les déchets recyclés constituent la matière première, et gage des vies futures dans la mesure où la fertilité en dépend.

Quelques agronomes, et non pas tous, attribuent à l'humus un rôle fondamental dans la fertilité et considèrent que la fertilisation "minérale" n'est durable et véritablement efficace que dans la mesure où l'on tient compte du rôle de l'humus, support des fermentations des résidus organiques dans le sol et fournisseurs, par là même, de substances de croissance des végétaux. Les engrais minéraux approvisionnent la croissance mais ne la commandent pas.

Suivant ces considérations, l'on est amené à promouvoir partout dans le monde, mais d'une façon adaptée aux climats, une politique de respect des résidus organiques à l'intention des fermentations microbiennes et des développements fongiques du sol. Je ne cesse de répéter: "le travail du sol est la principale, la plus indispensable des industries de fermentations! C'est également la principale des techniques d'épuration!"

WATER IN A WORLD OF EXPANDING RESOURCE DEMANDS*

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Water is an essential ingredient of human activities and often is a significant constraint upon them. This is due in part to primary dependence upon that small fraction of the earth's water, less than one-millionth of the total resource (Nace, 1967), which precipates as rain and returns via rivers to the sea. Throughout geologic time, this continuously cycling water has interacted with the atmosphere, the land and living things. Because precipitation patterns are irregular and components of the atmosphere and earth materials vary markedly from place to place, the interactions yield a wide variety of effects upon quantity and quality of water. There always have been salty rivers, muddy rivers, rivers with relatively high temperatures, oxygen-depleted rivers, and a wide range of ground-water qualities which could not be attributed to the activities of man. Human impacts, whatever their dimensions, are superimposed upon, and frequently are made more troublesome by, these natural patterns. The troubles can be expected to increase as populations expand unless corrective action is taken.

NATURE AND DIMENSION OF WATER USE

Man has affected water resources primarily by imposing subcycles on the basic hydrologic system. The significance of this imposition is apparent in water-use statistics of the United States of America (Murray and Reeves, 1970). When the Nation achieved independence, it was using about 3.8 million m^3 (one billion gallons) of fresh water per day, less than one-thousandth of its total average river discharge. In two centuries, this use has grown to 1.3 km^3 (350 billion gallons) per day—about 30% of the average river discharge. This is 75% of the estimated dependable surface water supply for the Nation and the portion withdrawn in seventeen semi-arid western states is 90% of the dependable supply. About 20% of the water withdrawn is lost in consumptive uses. Water use is continuing to increase at about 3% per year and may reach 1.7 km^3 (450 billion gallons) per day by 1980.

The use to which this water is put in the United States also has changed with time. In the beginning, it was diverted principally for domestic supplies. Now about 60% is used for industrial purposes, primarily for cooling steam-electric generators. This industrial water is recycled or reused an average of one-and-a-half times before it is returned to the

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rivers with accumulated heat and waste products. About 3% of it is consumed in manufactured products and evaporation losses.

Irrigated agriculture accounts for 36% of the Nation's present fresh-water use. About 59% of this is lost by evapotranspiration and seepage. The remainder returns to the source with an increased load of suspended and dissolved materials. This single use accounts for approximately 85% of the total consumptive use of water in the United States.

The qualititative significance of increasing water use is apparent in the fact that total withdrawal is the sum of a succession of downstream diversions (cumulative withdrawal). Each of these subcycles is likely to increase consumptive loss and the load of waste products returned to the river. A survey of the Delaware River Basin, located in the heavily urbanized northeast coast of the United States, showed that 254 industries of 10 different types sequentially were diverting water (Clarke, 1962). A similar study of the Verdigris River in the State of Kansas indicated a total withdrawal equal to 17 times the river's low-flow discharge (Clarke, 1962). Considerable change in river quality is inevitable under such circumstances.

WATER-RESOURCE TRENDS

With increasing water use, one would expect to find evidence of general significant degradation of water resources. However, such changes are difficult to detect; first, because corrective actions, such as sewage treatment, mitigate local impacts and second, because we lack the water data needed to assess long-term trends.

In a recent study (Steele and others, *in press*), the U.S. Geological Survey concluded that only 88 of its 5000 river testing stations scattered throughout 74 of 220 major drainage basins have accumulated appropriate data over sufficient periods to allow meaningful analysis of river-quality trends. At this relatively small number of sites, specific conductance, a measure of dissolved solids, was found to have increased significantly in 10 locations, decreased significantly at 5, and remained about the same at 73. Corresponding thermal data showed that average water temperatures decreased at 10 locations and increased at 3.

A similar report by the United States Council on Environmental Quality (1972) concluded that only 142 river-quality stations in the national network have records which meet that agency's criteria for trend analysis; namely, quarterly sampling over 8 or more years for sediment, salinity, organic indicators (e.g. dissolved oxygen), and nutrients. Analysis of these 142 records showed increases in nutrient levels at 47% of the sites and decreased dissolved oxygen at 20%. Dissolved oxygen increased at 17% of the stations. No other significant trends were noted.

EVIDENCE OF SIGNIFICANT WATER IMPACTS

Despite the limited number of long-term water-quality records, examples throughout the world show that human impact on water resources has been significant. A study of the Indus Plains in West Pakistan in the late 1950s and early 1960s (Revelle, 1964) concluded that from 20,000 to 40,000 hectares of irrigated land were being lost annually to water-logging and salination. Although this problem is being overcome, at least temporarily, by wells which recycle ground water to the land for simultaneous salt leaching and irrigation, the eventual effect of this process on water quality is still uncertain.

Long-term records compiled on the Colorado River Basin, a semi-arid region of western United States, show that average river salinity has doubled since irrigation started in the early 1900s (Irelan, 1971). Systematic control of the river's flow, diversion to points outside the basin, and allocation of the waters to consumptive uses have essentially eliminated all discharge to the ocean. The Colorado River is thought by some to be already over-committed in terms of average flow, and increasing salinity will require major corrective action.

There also are well-documented examples of industrial effects upon surface waters. The Mahoning River, which flows from Ohio into Pennsylvania, United States, and services a significant percentage of the Nation's steel production, has undergone measurable changes over the years. A U.S. Geological Survey study (Bednar and others, 1968) revealed maximum summer water temperatures of 26°C above the industrial complex and 42°C below it. At the downstream site, dissolved solids content was about 50% greater, total iron was 10 times greater (20 mg/1), and the dissolved oxygen content was consistently below saturation, sometimes no more than 1 mg/1. Similar examples can be found in highly industrialized areas in other parts of the world.

Numerous serious temporary effects of urban wastes appear in the records. During the mid-1940s, a 12-mile reach of the Delaware River was completely devoid of oxygen, a condition which has markedly improved because of sewage treatment. New York City in the same heavily populated coastal area now is spending $1 million per day in a $4 billion program to correct similar dissolved oxygen problems in its harbor areas. Counterparts of such urban impacts upon water quality occur on a global basis.

The Great Lakes in north central United States provide an excellent example of steady increases in conservative solutes, such as sodium chloride, which are not easily mitigated. Except for Lake Superior, which is relatively free from large-scale urban and industrial development, solute concentrations have increased in all the lakes since the turn of the century. In 1962 they ranged from 23 to 28% higher than they were in the early 1900s (Pincus, 1962), and some now are approaching 40% (Beeton, 1969). These changes, despite rather uniform geology and differences in estimated ages of the lakes (2200–9600 years), would appear to rule out natural causes of the change. The fact that greatest increase has occurred in lakes with the highest ratios of coastal population to water volume would tend to confirm human impact on these great natural reservoirs which contain 14 times as much water as all the rivers of conterminous United States discharge in a year.

Although we have depended primarily on surface waters, underground waters also show evidence of overuse and degradation. Troublesome land subsidences in Venice, Italy, numerous urbanized areas of Japan and irrigated farmlands of California, United States, are typical consequences of withdrawing water from certain aquifers more rapidly than it can be replenished. A 80 km^2 area east of Tokyo, with a population of 2 million, already is more than 2 m below sea level and must be protected by dikes (Poland, 1972). In the San Joaquin Valley of California, United States, 13,470 km^2 have subsided as much as 9 m (Poland, 1972). Salt-water intrusion of ground-water aquifers in many coastal areas show that such overdraft also can have very troublesome water-quality implications.

Difficulties can arise even when the ground-water level is maintained by natural or artificial recharge. The nitrate content of a principal fresh-water aquifer 130 m below the surface of New York's Long Island locally is increasing at the rate of 3.5 mg/1 per year and has reached a concentration of 50 mg/1 in some areas—60 times the concentration of 50 years ago (U.S. Geol. Survey Prof. Paper 800-B, 1972). Whether this example is typical or not, it indicates the potential of agricultural runoff and septic tank seepage for influencing

ground-water supply. The current trend toward surface and underground disposal of municipal and industrial wastes adds a new and potentially troublesome dimension to ground-water problems. In the United States alone, there are over 200 active industrial waste-disposal wells.

IMPLICATIONS OF GROWTH

Energy consumption is an indicator of resource development and related water demand. Use of energy in the United States has increased at least 100-fold since primitive times, primarily because of industrialization in the recent past. In 1973 it amounted to 75.6 quadrillion Btu, the equivalent of 1 ton of coal for everyone on earth. If it continues to grow to 190 quadrillion Btu by the year 2000, as predicted, there undoubtedly will be an equivalent increase in water use. The impact on water will be even greater if the proportion of energy supplied as electrical current doubles and half the electrical energy is generated by conventional nuclear fission and breeder reactors, as expected. Each of 188 nuclear plants now in planning or development stages (U.S. Atomic Energy Commission, 1974) would require 42 m^3 of water per second for once-through cooling. A recent study (McDonnel Douglas, 1974) concluded that the water withdrawal needed to sustain the expected growth in the United States to the year 2000 may exceed dependable supply in more than half of the twenty-one hydrologic regions and that water consumption alone may exceed dependable supply in a quarter of them. Such shortages would be particularly troublesome because they will occur primarily in the semi-arid West which contains 85% of the nation's low-sulfur coal and virtually all of its vast oil shale deposits which are needed for clean energy production. A 7 million m^3 per day coal gasification plant, with an energy output equal to that of a 1000-MW electrical generator, will require the same amount of cooling water as the generator and a 1 million barrel (158,990 cubic metres) per day oil shale converter will require up to 7.5 m^3 per second—about 3 barrels of water for each barrel of oil produced. Because this geographic area contains most of the nation's irrigated farmland and a high percentage of its most scenic recreational areas which depend heavily upon water, there will be difficult trade-offs.

Increasing needs for food and other agricultural products obviously will have very important water-resource implications. Whatever the increase in world populations between now and the end of the century, at least a proportional increase in food supply will be needed. Because one-third of the Earth's land is semi-arid or desert, and climatic cycles cause periodic droughts in humid areas, increased food production probably will require increased irrigation. Also, there will be pressure to increase yield per acre through the use of synthetic fertilizers, pesticides, and farm machinery. This will increase energy demand and impacts on quantity and quality of water. Intensive agriculture in the United States has increased yields up to 50% per acre in two decades, but it is estimated that about 10 calories of fuel energy are expended for every calorie of food energy put on the plate (Bryson, 1973).

THOUGHTS FOR THE FUTURE

One cannot consider the implications of a relatively finite water supply and rapidly increasing water demands without recognizing the need for improved management and sur-

veillance of water resources. Increased emphasis on efficient water use is an important part of this and, like pollution control, must receive more attention in the future. There still are ample opportunities for extending fresh water supplies through improved efficiency in irrigation practices, more conservative industrial processes, and use of saline waters and waste water wherever practicable. Pricing water supplies to reflect their true costs and discourage waste also has much to offer. Because water is recognized as a very real constraint on development of other resources, such as energy, the United States Department of the Interior has adopted a policy which will require planning for water-use efficiency in resource development which involves that agency.

Beyond the need to conserve water resources and to extend them through technological innovations, there is urgent need for more meaningful water monitoring. A proper system should provide the minimum number of measurements needed to develop a reasonably reliable indication of the rate and direction of change in quantity and quality of the resource. The United States Geological Survey proposes to do this with an accounting network of 540 test sites on the Nation's 3.5 million miles of surface streams. Information collected in a hydrologic bench-mark program of fifty-seven small river basins relatively unaffected by man, and a series of modeling studies of rivers representing various natural and cultural environments will be used in part for interpreting the resulting data.

INTERNATIONAL RESPONSIBILITY

In a world which must share its resources, water problems—wherever they occur—eventually will affect all of us. Thus, all should share the burden of assessing trends in water resources and mitigating those which are undesirable. Effective monitoring and improved water-use efficiency can best be achieved by aggregating the wisdom of the international community. The forum assembled here recognizes this need. Hopefully, its deliberations will prove to be an effective beginning of the task which lies ahead.

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THE ENVIRONMENTAL AND SOCIOLOGICAL IMPACT OF RECYCLING OF AGRICULTURAL WASTE BY LAND USE

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INTRODUCTION

New ways of disposing of animal and human effluent are now being demanded in the United States because of the overloading of streams, lakes and rivers, and even our oceans, with pollutants. The nitrogen, phosphorous, and organic matter that now pollute our bodies of water are really resources out of place. Green Valley Farms has taken the concept of recycling, refining, and utilizing these resources in a beneficial manner to grow crops, instead of allowing these resources to reach either the surface or ground water. If these nutrients are allowed to reach either the surface or ground water, they are then classified as pollutants and are lost to mankind's benefit.

At the Colloquium on Primary Materials Supply and Recycling held at Orléans-la-Source, France, September 27–29, 1973, part of the general conclusion states: "At one extreme, in the rich countries, solid wastes amount to an average of 20 tons per person each year. This includes about 10 tons of agricultural waste, 8 tons of mineral wastes and more than 2 tons of urban refuse (municipal, commercial, domestic)." Of the waste produced per person in the highly industrialized nations, 50% is agriculturally derived. This factor points out the great need for the recycling of agricultural waste to maintain a clean environment and an adequate and nutritious supply of food for the world population. Green Valley Farms has undertaken a research and development program to recycle cattle wastes back to the land in order to enhance the environment and to help provide a better and more nutritious food supply for our neighbors.

Green Valley Farms is located in New Garden Township, Chester County, Commonwealth of Pennsylvania, United States of America. This is in the metropolitan region of the eastern United States which is commonly termed "megalopolis" and reaches in distance from Boston, Massachusetts, in the north, to Washington, the capital of the United States, on the south. The very location within this urban megalopolis area makes the results and acceptance of Green Valley Farms' concept of land use by the community such an exciting prospect for the future.

Figure 1 shows the location of Green Valley Farms in relation to New York City, Philadelphia and Washington. Figure 2 shows the area immediately surrounding Green Valley Farms. Figure 3 shows the layout of the farm, and the numbers indicate the monitoring stations. Figure 4 is a picture of the corn which was treated with effluent, showing the

excellent results. Figure 5 is Dr. Dale Beker, an agronomist and soil scientist from Penn State University, and Charles Magee, microbiologist from Green Valley Farms, looking over the effluent irrigated test plots, 1973.

SHORT HISTORY

Green Valley Farms was established in 1709 and is an original grant from William Penn and has been in continuous operation for 265 years. My grandfather purchased the farm in 1904 and it was operated by him and my father as a dairy farm until 1945 when I continued the operation, wholesaling the milk to the city of Philadelphia.

The location of this farm in New Garden Township, in a rapidly urbanizing area surrounded by a population of over 4000 people, is a microcosm of almost any metropolitan area, in that it has much diversity such as heavy manufacturing and fabricating plants, trucking industry, the world's greatest mushroom-growing area, large horticultural greenhouses producing some of the finest roses for the metropolitan markets, canneries, research and development facilities, electronic manufacturing plants, an airport, golf courses, offices and businesses, stores and suburban homes in the $30,000 to $100,000 price range.

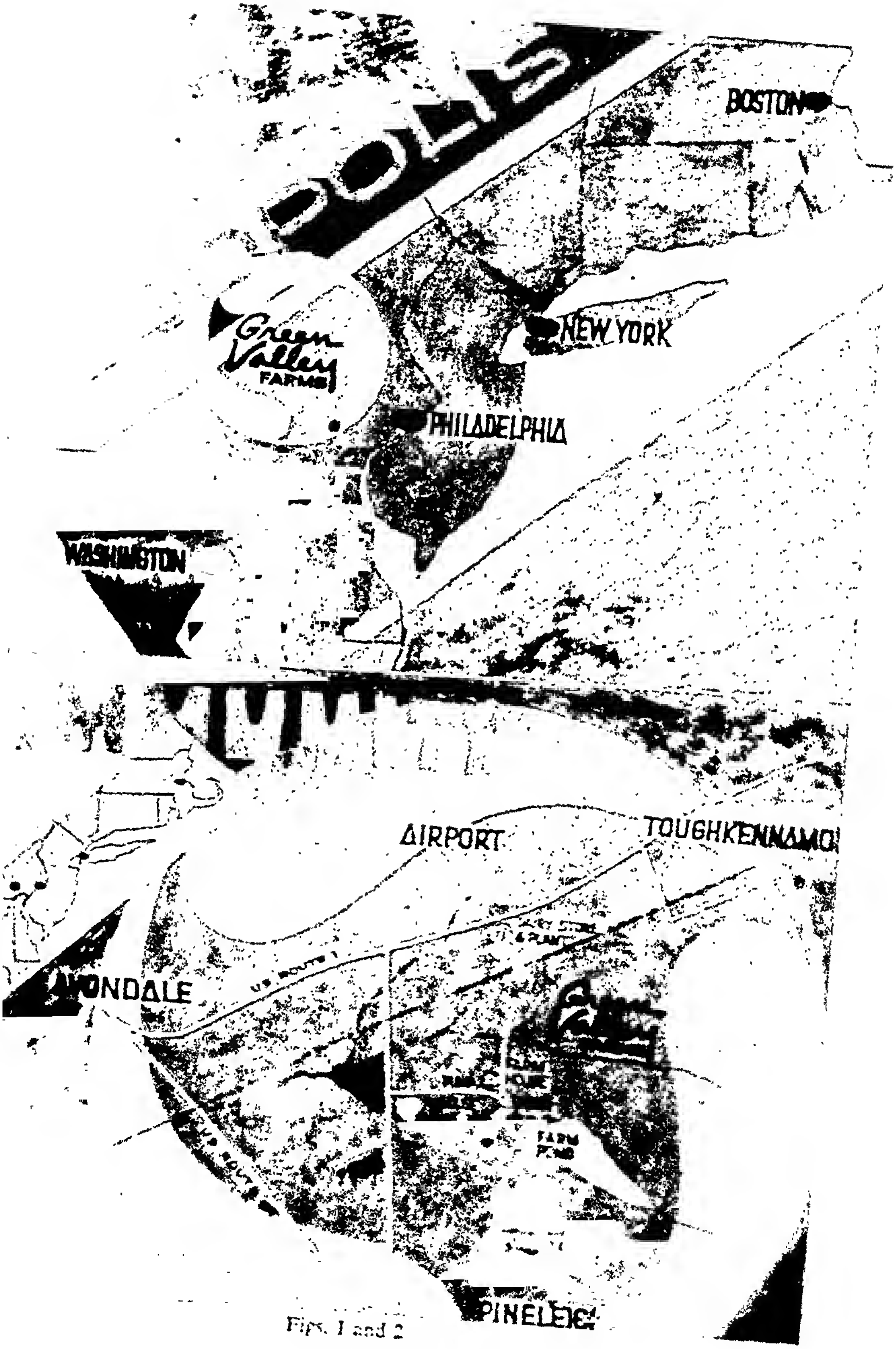
During these 70 years, the whole area has been changing rapidly from rural to urban. As this urbanization came upon us, Green Valley Farms made the decision to remain agricultural in an urban area, and I began to develop the concept of land use to utilize the land to its utmost agricultural capacity. Due to the drought in 1955, the first step towards this goal was the development of water resources by irrigation ponds and the first utilization of spray irrigation in maximizing crop production.

In 1960 we decided to process the milk and sell directly to our neighbors from our plant and store which we built on the farm. The slogan on the jug is "From the blade of grass to the glass". About this time I began to take an active interest as a township supervisor in improving and enhancing the environment of the community. When I was elected to the General Assembly in 1964, I continued this concern with my colleagues in Harrisburg.

These incidents all collimated into the idea of recycling cattle waste by establishing waste stabilization ponds and in a beneficial and economical way apply the animal waste to the ground through a spray irrigation system.

Green Valley Farms recycling program renovates the animal waste by filtering the treated effluent through the soil. The plants utilize the pollutants, i.e. nutrients such as phosphorous, nitrogen, ammonia, and organic matter, as part of their food supply. When we discussed our ecological blueprint with Dr. Melnick of Baylor College of Medicine, Houston, Texas, he likened our treatment system to a water refinery, taking a crude product (the cattle waste), treating it in stabilization ponds as part of the primary and secondary treatment and then finish refining the product by applying the treated effluent to the ground and crops, and thus extracting the final amount of nitrogen compounds, phosphorous, and organic matter. In this manner, the plants and soil are the final extraction process, giving us an end product of exceptionally high-quality water returned to the aquifer ready to be drawn upon again for mankind's usage.

Green Valley Farms established a research and development program to determine the environmental impact of land treatment on our environment. At the same time, Pennsylvania State University was developing "The Living Filter" concept. In 1967 we met with Dr. Kardos and his group at the Pennsylvania State University and began to develop the Green Valley Farms recycling system together with a water-quality monitoring program.


BOSTON
NEW YORK
Green Valley
FARMS
PHILADELPHIA
WASHINGTON
AIRPORT
TOUGHKENNAMO
AVONDALE
PINELEIG

Figs. 1 and 2

With the help of Dr. Kardos, Dr. Parizek, and Dr. Soper and the GEO Technical Services, our design engineer of Harrisburg, the system was developed and built in 1969 and put into full operation in June 1970.

RECYCLING PROGRAM OF AGRICULTURAL WASTE

The first full application of the recycling concept was the planting of sudan the latter part of June 1970, which grew 4 feet in 10 days under the spray irrigation treatment. Our basic raw material to be recycled is the manure effluent discharged by 200 head of milking cows into two stabilization ponds. The effluent is composed of the manure and urine excreted by the animals, the wash water to cleanse the concrete pads, the milkhouse and milking parlor wastes.

This basic effluent, as monitored by Dalare Associates, in the first stabilization pond has a total fecal coliform count of between 2 and 4 million, which is reduced in the second stabilization pond to a range from 240,000 to 240 fecal coliform, depending upon sunlight and holding time. The effluent in the lagoons has shown no NO_3, but has a range between 85 and 72 ppm of ammonia in the first and second lagoon. The 5-day BOD can average as high as 500 to 600 ppm in the first lagoon to approximately 200 ppm in the second lagoon. Dissolved solids in the primary lagoon range from 1100 to 1200 ppm and decrease to 800 in the secondary lagoon. Phosphates range from 100 to 60 ppm in the first and second lagoon.

This biologically treated effluent is applied to the crops and woodlands by a spray irrigation system. The results of our testing show that the growth of the crops and the woodland removes 99.6% of the ammonia in the treated effluent (there is no NO_3 in the stabilization ponds) as well as 99.6% of the phosphates as PO_4, 5-day BOD, total and fecal coliform, leaving a very high-quality water for use again.

The system meets the tertiary requirements of the Pennsylvania Department of Environmental Resources, Delaware River Basin Commission, and the no discharge goals of the Environmental Protection Agency of the United States. We, at Green Valley Farms, have been exceptionally pleased with the high degree of efficiency of our refinery in the renovation of the treated effluent.

MONITORING PROGRAM

In its research and development, Green Valley Farms established a quality-control program for its recycling of agricultural waste which includes an extensive chemical and biological monitoring system from the very beginning of the refining process to the final finished product of high-quality ground water returned for man's use. The chemical monitoring program consists of dissolved oxygen, dissolved solids, phosphates as PO_4, nitrates as NO_3, ammonia plus nitrates as N, 5-day BOD, and ammonia as N. A spectograph analysis is done at periodical intervals. Also included are aerial infrared photographs taken for further analysis of crop growth and management.

One of the first epidemiological programs in the country for a spray irrigation system was developed in 1972 with Dr. Joseph L. Melnick, Chairman of the Department of Epidemiology and Virology, and Professor Craig Wallis, Professor of Epidemiology and Virology, Baylor College of Medicine, Houston, Texas. Both gentlemen had developed

various monitoring apparatus capable of detecting one virus particle per 100 gallons of water. With this exceptionally fine capability of monitoring, Dr. Melnick and Professor Wallis were asked to help us with our virus monitoring program to determine if any viruses were present that are pathogenic to mankind. They also monitored the ground water and the streams within our spray irrigation area for any pathogenic viruses. To this date, none have been found.

The stabilization ponds are monitored on a weekly basis by taking samples from all areas of the pond. Also a program to monitor for *shigella* and *salmonella* organisms was established, including typhoid. None have been found to date.

Green Valley Farms spent a great deal of time designing a method of catching the treated effluent from the irrigation sprinkler guns. This collected effluent was put through the virus monitor. Again, no viral pathogens, *shigella* or *salmonella* organisms were found.

The program put in practice at Green Valley Farms is considered one of the first of its kind in the country, and many regulatory agencies, environmentalists, scientists, and other interested people have spent many hours discussing the development of the virus-monitoring system for assuring the safety of the spray irrigation procedure.

It is our belief that the program developed for us by the Department of Virology and Epidemiology, Baylor College of Medicine, could be duplicated and used on a worldwide basis to provide environmental health monitoring in the parameters of viruses in land-treatment systems.

With proper monitoring, there is no longer any reason for withholding human waste-water, properly treated to inactivate any viral or other pathogens that may be present, from spray irrigation. Key to the success of such a program is (1) the use of proper treatment to inactivate viruses and (2) the regular monitoring to assure the community that the treatment is effective.

ENVIRONMENTAL IMPACT

Recreation

Green Valley Farms is located within a community of approximately 4000 people which makes it a good test model for the sociological aspects of a community's response to a land-treatment system, i.e. recreation, visual aesthetics, open space.

Figure 2 visually describes the community around Green Valley Farms. The upper fresh water lake has provided a fishing area for local children and, on occasion, their parents. The irrigated woods is a recreational and nature area for the community around it. Many species of birds and wildlife are found in the woodland and area immediately surrounding it. The areas irrigated in the wintertime and the ice patterns that develop from spraying in the freezing weather provide a very pretty panaroma of a winter woodland landscape. The spray irrigation of the woodland not only feeds the trees, but by keeping the area natural, provides an excellent growth of berries and seeds and nuts which birds and wildlife feed on. This extra food supply seems to be one of the key factors to attract and keep the wildlife in the woodland and farming area.

In the spring and summer the wild flowers and woodland plants, as well as the lovely woodland foliage, create a beautiful conservation area. The effluent from the spray irrigation

is feeding the woodland area and makes a very delightful nature area as well as a summertime playground for the children when they are out of school. In the fall, sportsmen train their dogs in the general area, and when hunting season arrives, pheasant and squirrel are in plentiful supply. We have posted the large pond so that the mallard ducks, canvasback, and other species as well as the Canadian geese are protected. Horseback riding through the woods and the surrounding area is a year-round activity. This nature center and wooded area is in the center of a very heavily urbanized area and actually pays revenue to the township through a land tax. We have coined a phrase and have used it in many of our talks and seminars—"Taxpaying open space".

With proper planning and proper management, the results we have seen in the last 5 years at Green Valley Farms indicate very strongly that the enhancement of the environment by recycling of animal and/or human waste provides tremendous potential for recreational and aesthetically pleasing open space for communities and does not place a burden on the taxpayer. Again, we see the theme of nature and man working in harmony with each other to the greatly enhanced benefit of mankind.

The community's response to land treatment has been a very fine one. We feel this can be duplicated in many areas of our country and throughout the world. It is of prime importance that the community be told of the environmental enhancement of a land-treatment system which is of proper design and employs a good management—that it can be an asset to a community by improving the environment as well as providing revenue for schools and community services.

Agriculture

Green Valley Farms has been irrigating cropland with fresh water since 1955, and in the 1960s with the help of the Pennsylvania State University began to develop a land-disposal system incorporating cattle wastes which had been treated in three stabilization ponds to a high degree of treatment and then released into the stream. We felt this was a tremendous waste of vital resources (both organic and chemical nutrients) which could be used on our land. We consulted with Dr. Kardos, Dr. Parizek, and Dr. Soper of the Pennsylvania State University who helped us develop a living filter system and a monitoring program for surface and ground water. This included streams, springs, shallow monitoring wells and deep monitoring wells.

In 1970 Green Valley Farms started an active land-treatment program which eventually evolved and developed into "An Ecological Blueprint for Today".* As previously stated, Dr. Melnick and Professor Wallis of Baylor College of Medicine have made possible the most extensive public health monitoring system for any land-treatment system in the country. As we developed our land-treatment system, working very closely with governmental agencies and the academic community, we found to our surprise that we were enhancing crop production to an extremely great extent. In meeting after meeting, we had been told that land-disposal systems are good for just short periods of time. We are happy to report that just the reverse was happening and that our crops were mining the fertilizer, nutrients, and organic matter faster than we could apply them. It was at this point of time that we consulted with Dr. Dale E. Baker of the Pennsylvania State University

* Copyright, 1972. Benjamin J. Reynolds, Avondale, Pennsylvania. A Manual of Waste Treatment Using Spray Irrigation: *An Ecological Blueprint for Today.*

and requested his help in developing a program that would be geared specifically to maximizing food, crop, and timber production from a land-treatment system.

We at Green Valley Farms had been interested in the use of aerial infrared photography for a number of years which first put us on the trail of the mining effect of our plants. To the environmentalist, this is an exceptionally important item of the whole concept in that the plants utilize and renovate the applied effluent before it can reach the ground water.

In 1972 Dr. Baker began to work with us to develop a system of land treatment that would maximize crop production as well as bring about the highest degree of waste-water renovation possible. The research work done by Dr. Baker during 1972 and 1973 proved conclusively that the treated effluent crops were indeed mining the nutrients very rapidly from the soil. With the aid of his staff, Dr. Baker is now in the process of developing a management program which consists of adding nutrients to balance the treated effluent. This correctly balanced effluent results in maximum crop production with the hybrid seeds and trees which are available to us today.

The work accomplished by Green Valley Farms, Dr. Baker and his colleagues indicate a number of significant items which can have a tremendous bearing on the future of mankind and the quality of life that we will be able to enjoy. At this time, I would like to list the very specific developments that occurred at Green Valley Farms during 1973 and their relation to the above comment relative to mankind.

1. Due to our program, we were able to maximize soybean production to 76.6 bushels per acre. The national average is 28 bushels per acre. This high yield was unexpected. Our check plot yielded 27.7 bushels.

Soybeans are one of the most versatile crops now known to mankind. The production of soybeans holds a key to the protein needs of the world. They can be eaten as is, as a protein food, or used as a supplement to enhance other foods, or they can be fed directly to animals to make meat protein. The greatest threat to the good health and nutrition of the world is the lack of protein for our young people and our older people. We feel strongly that this research which led us to the discovery of an exceptional soybean production must be amplified by many research institutions and agriculturists the world over. When we consider the anticipated increase of three billion people to our world in the next 26 years, time is running out.

2. The second development verified by extensive research is that the treated effluent sprayed upon the sudan grass at Green Valley Farms significantly raised the digestible protein content by as much as 30%. This, too, bears a direct relationship to protein for mankind because it lessens the need for edible protein for livestock. The sudan plant was able to synthesize the breakdown of the ammonia in the soil from the effluent into a much higher digestible protein content than is normally expected from this type of grass in our region. Again, it appears we are just beginning to scratch the surface in the utilization of pollution in a highly beneficial manner to mankind.

3. The third major finding entailed the difference between the effluent-treated ear corn and the nontreated ear corn. The nontreated corn produced a low of 75 bushels, whereas the effluent treated corn (same variety of seed, same field) produced a high of 152 bushels. Due to a very wet and cold spring, this corn was replanted on June 10, which was approximately 30 days later than usual for planting in southeastern Pennsylvania. Dr. Baker believes there is a potential of obtaining 200 bushels per acre and, in an exceptionally good year, even higher.

All test programs were significant at 95% and 99% levels, per Dr. Baker's report.*

With this documented research, we feel very strongly that if the nations of the world start immediately to look at the use of land treatment where wanted and applicable for maximizing crop production, we can provide a better food supply than is now grimly projected for the future.

Grassland Farming

Results of our research and work show that grassland farming using the application of effluent by land treatment will become one of the most important aspects to be considered by agronomists in the near future for increased food production.

Much of the grasslands in the world are not suitable to be intensively cultivated and plowed year after year because of their topographical features. The soil-conservation programs the world over indicate it is best to keep much of the grassland and woodland in its natural state in order to prevent environmental erosion. These grasslands are often of poor agricultural capabilities as compared to class 1 and 2 farmland. The grassland hillsides can make an ideal place for the application of both animal and human treated effluent and sludge. Usually the best method of harvesting the crops from grassland and steep ground is by cattle and sheep. The alternative to raising of animals on much of the grassland area would be to terrace the land which would be prohibitive in both time and energy. The terraced land would prevent soil erosion.

Our research has shown that we can raise the protein content of certain grasses, making it even more appealing to pasture meat and milk animals on this poorer-quality ground. Working very closely together with the soil scientists, agronomists, and people actively engaged in animal husbandry, we can utilize land treatment on our grassland areas throughout the world, thereby providing mankind with a much greater supply of red meat than heretofore thought possible.

Finally, the work at Green Valley Farms has shown that timber production of both hard and soft woods has vastly been increased by the use of treated effluent. As the world demands more and more of lumber and paper products, much of the marginal ground that has gone out of production can be brought back into full-scale environmentally safe production through the raising of trees for timber and paper by the land treatment method.

SOCIOLOGICAL IMPACT

As part of this paper, I would like to present an editorial from the *Philadelphia Inquirer*, August 24, 1974, entitled "Famine is a World Wide Problem" with the subtitle "The Mark of Cain".

Three basic premises were pointed out in this editorial—a climatic shift produced by the cooling of the earth—the huge rise in the world price of petroleum—the geometric expansion of the world's population.

The editorial mentions that the cooling of the earth has caused severe droughts across much of Africa and Asia. The extremely high price of petroleum products has contributed

* Baker, Dale E. *et al.*, "Effect of Waste Disposal on Crops, Soils and Wate [illegible] the use of dairy cattle manure effluent for maximizing crop production".

drastically to the rise in price of fertilizer which is so badly needed to provide adequate supplies of nutritionally balanced food. The geometric expansion of the world's population applies the same demand geometrically upon our food supply.

The research and development that has been carried on at Green Valley Farms, we feel, will have a tremendous beneficial social impact upon the world in the years to come. I would like to stress them in the following manner:

1. Pollution abatement—removing the pollutants from the animal wastes, thus providing a better and cleaner environment.
2. Removal of the nutrients and organic matter from the animal wastes, thus providing an exceptionally high quality of renovated water to be utilized by mankind for his many needs and uses.
3. The increased crop production resulting from items 1 and 2 (the recycling of agricultural wastes at Green Valley Farms) showed very specifically our ability to double corn production and triple soybean production and vastly increase both the tonnage and protein content of grasses.

The net effect of the ability to enhance crop production by recycling of agricultural wastes would be to provide a diet substantially increased in both energy and protein. Our civilization is very close to a diet so low in energy and protein content that it can cause tremendous physical and mental damage to many of our peoples throughout the world. This not only can happen to underdeveloped countries but, with the changing climatic and economic factors in the world today, can happen also to our developed countries. We feel very strongly that our concept of recycling animal waste can be applied as well to recycling of human wastes with the same results and can be one of the major factors in meeting the world food crisis that appears to be bearing down upon us. Not only a very beneficial and environmental impact, but a beneficial sociological impact to our world's people would seem to be the net result of our research and development program.

GREEN VALLEY FARMS

Testing and Monitoring

On October 19, 1971, Green Valley Farms had a spectrogram done by Dalare Associates on the agriculture waste in the second lagoon (station no. 11). The laboratory reported there was no indication of any heavy metal or toxic deposits in the lagoon.

The week of October 14, 147 tests were run on twenty stations including total coliform, fecal coliform, dissolved oxygen, dissolved solids, nitrates (NO_3), phosphates (PO_4), biological oxygen demand and chemical oxygen demand. We were very pleased with the test results on both ground water and surface water.

Green Valley Farms has conducted aerial infrared photographic surveys of the waste water renovation project. These surveys were started in the spring of 1971 and are continuing to date.

Many state, federal and local agencies and other interested watershed and conservation groups have visited our site. We are pleased with the interest shown in our project and will continue to welcome interested groups.

DISCUSSION

BROWN: Thank you, Mr. Reynolds for that interesting paper. I was somewhat startled and somewhat pleasantly surprised by the major increase in soybean yield. I have been told that the soybean has responded, but very slowly in research in increasing yield and that it responds to liberal application of fertilizer rather slowly as well, simply because in part the symbiotic system fixes its own nitrogen. Do you have any clue as to the reason for this increase of yield?

REYNOLDS: Yes, we are beginning to sift the data generated by the soybean test plots at Green Valley Farms research and development project. This data was fed into a 360 computer at Pennsylvania State University and showed that the test plots which were sprayed with effluent plus nitrogen yielded at the rate of 76.6 bushels per acre—a very dramatic increase—as opposed to only 27 bushels per acre on the non-treated test plot. As pointed out in a national magazine, the average soybean yield in the nation now is 28 bushels per acre per year and the average increase per acre per year is only 1%. The yield of the soybeans on the effluent-treated plots at Green Valley Farms was 177% greater than that of the control plot.

It has been observed in the test plots that the nitrogen-fixing nodules are much more extensive on the effluent-treated soybean plants than on the non-treated. The soybean plant is much larger with a far greater leaf area in the effluent treated than the check plot.

Putting all these factors together, one can begin to draw some preliminary conclusions as to the "Why?" of such a large yield. These would be (1) the effluent-treated soybeans become a much higher efficient plant because of the larger increase in the nitrogen fixing nodules, (2) the larger leaves enable the plant to use the sunlight much more efficiently, (3) the plant itself is much sturdier and larger which allows more pods per stalk than normal. Some of the stalks that we recorded had as many as 185 pods.

BROWN: But I gather that the specific biological or chemical reason for this is not known yet.

REYNOLDS: No, the specific biological and chemical reasons for this increase have not been ascertained as yet. The physical data, i.e. the larger growth, more nitrogen-fixing nodules causing maximum yield would strongly suggest a very concerted effort be made by the scientific community to determine the specific biological and chemical reasons for such a large yield, because soybeans are one of the world's most important crops.

DYKE: I was wondering, Dr. Reynolds, if you can tell me, have you done any work with the manure as it leaves the animal, as opposed to irrigation? . . .

REYNOLDS: Yes, Dr. Dyke. We have applied the manure from the cow to the farm production crop in a number of ways. First, it has been applied as you call it "neat"—spread on the fields the same day the manure was dropped. Secondly, the manure was stacked for periods ranging from 1 week to 2 months and then spread upon the field. Thirdly, the manure was biologically treated in stabilization ponds and then pumped out and sprayed on the fields under high pressure. The growth results of the irrigated manure far surpassed any other method of recycling the manure waste.

DYKE: You're right to put the stuff on the land. I'm quite sure of that. What I was getting at . . . and you're right to balance up the mineral values. This is essential. If you get a balanced plant food theoretically, no matter how much you put on the land, it must be beneficial. I was trying to get at the economics of handling hydraulically. Let's say at 1% dry matter . . . you're handling, say, 9 times the volume you need to handle if you take it at a 10% value DM as it leaves the animal. In other words, is there economic cause for using water simply as an aid to transport?

REYNOLDS: Yes, there is an economic cause for using water as an aid to transport the manure. First, it is more economical to move the manure by pipeline that it is to move manure into the field one load at a time. Secondly, it is the most efficient way to handle the recycling of agriculture waste with the extra benefit of using the water that transported the manure to enhance crop production and recharge the ground water after the plants have taken out all the nutrients and leaving a high-quality water to recharge the ground water.

DYKE: And you have a dry land situation? You see in the U.K. we are going off irrigation . . . this is what I'm getting to finally . . . we're going off spray irrigation in favor of handling it neat because of the energy cost of hydraulic transport and the fact that we cannot spray in certain conditions—when the crops are growing, of course, and in the winter when you have a high water level in the soil and run off to stream. This is one of the great problems we have in the U.K. where we have a very high rainfall.

HERBERT: I have a very simple question, really, and Mr. Hayes touched on it slightly. These wastes are generated every day, 7 days a week. How do you handle them in very inclement weather?

REYNOLDS: Mr. Chairman, may I take a moment to answer that? There are several ways. We have a storage capacity of approximately 4 million gallons that we can store for about 30 days. We use in the United States—I was very fortunate in stopping in the United Kingdom to see your sludge-disposal system at Maple Lodge—we irrigate at 0°F. We have been able to, in working with Penn State we use a different type of gun—but we spray into the air and make ice on the trees. We use woodland. This, Dr. Cardos tried to explain to me and I know that Dr. Fairisack understands it much better than I do . . . but the slow melt does not allow it to run down the streams because we monitor all the streams and we also monitor

EFFECTS OF RECYCLED WASTEWATER ON THE QUALITY AND USE OF GROUND WATER ON LONG ISLAND, NEW YORK, U.S.A.

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Abstract. Ground water is the sole source of potable water for the 2.6 million people in Nassau and Suffolk counties, New York. Ground-water recharge by recycling large volumes of wastewater from cesspool leachate has caused widespread deterioration of ground-water quality. In some areas, concentrations of nitrate exceed the standard recommended by the U.S. Public Health Service for drinking water, 10 mg/l, as N. Planned and controlled recycling of highly treated wastewater through ground-water recharge can conserve water and help manage the deterioration of ground-water quality within economic and public-health constraints.

IMPORTANCE OF GROUND WATER ON LONG ISLAND

Long Island is an elongated land mass of about 3600 km^2 (1400 mi^2) just seaward of the north Atlantic coast of the United States mainland (Fig. 1). Politically, Long Island is divided into four counties—Kings, Queens, Nassau, and Suffolk counties. The two westernmost counties, Kings and Queens, are part of New York City and are densely populated. About 4.2 million people (New York State Division of the Budget, 1973) live in the 500 km^2 (193 mi^2) area of these two counties. Most of their water needs are supplied by the New York City water system with water from distant surface sources, but an average of 4.01×10^5 m^3/day (106 Mgal/d) (New York State Department of Environmental Conservation, 1973) of ground water was pumped locally for some of the industrial and public-supply needs in 1972. In contrast, ground water is the sole source of supply for the 2.6 million people inhabiting the 3100 km^2 (1200 mi^2) area of Nassau and Suffolk counties—the two easternmost counties. There the population is unevenly distributed, and the population densities range from about 60 persons/km^2 (153/mi^2) at the east end of Suffolk County to 2500 persons/km^2 (6481/mi^2) in western Nassau County (Long Island Lighting Co., 1973).

In 1972 ground-water withdrawals in Nassau and Suffolk counties averaged 1.41×10^6 m^3/day (373 Mgal/d). Distribution of the pumpage by use was: public supply, 78%; industrial, 19%; and agriculture, 3% (Fig. 2). Population and per capita demand—currently about 380 l/day (100 gal/d) for non-industrial purposes—are expected to continue to increase. By the year 2000, the total water-supply needs of Nassau and Suffolk Counties are estimated to be between 2 and 2.25×10^6 m^3/day (528–595 Mgal/d) (Temporary State Commission on the Water Supply Needs of Southeastern New York, 1972). Part of the future water requirements of this area will probably be met by carefully controlled, large-

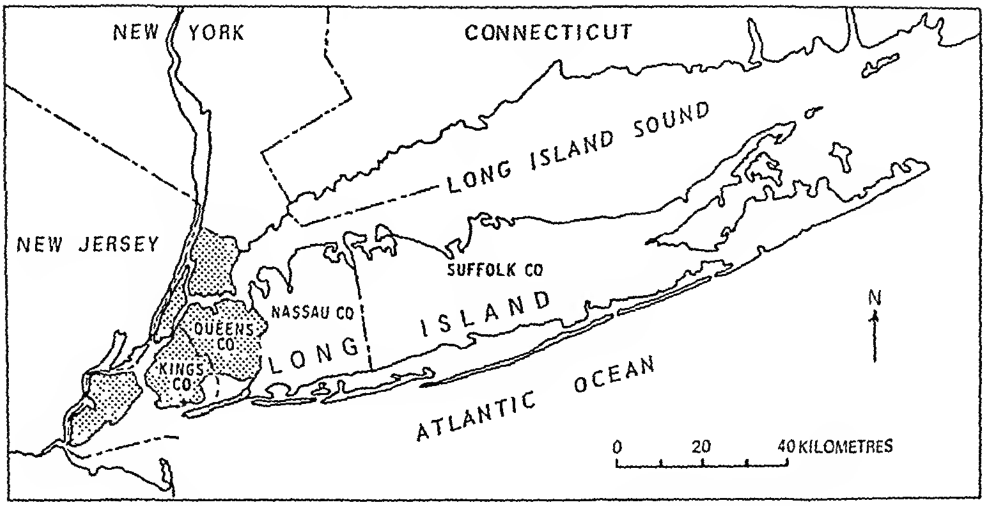

Fig. 1. Location and political subdivisions of Long Island, New York. Stippled area is New York City, N.Y.

scale recycling of water reclaimed from municipal sewage. Until now, part of the water needs have been met inadvertently by unplanned and unregulated large-scale recycling, through ground-water recharge, of water from domestic wastes. This practice has caused certain water-quality problems described later.

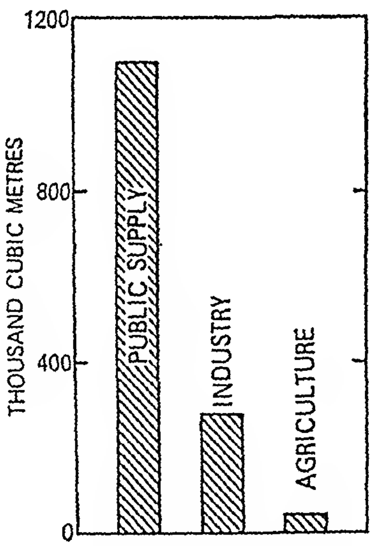

Fig. 2. Average daily withdrawal of groundwater by use in Nassau and Suffolk counties in 1972.

HYDROLOGIC SETTING

Mean annual precipitation on Long Island ranges from 1020 to 1270 mm (40–50 in) and averages 1120 mm (44 in) (Franke and McClymonds, 1972, p. F19). A little more than half of the mean annual precipitation, or about 580 mm (23 in), recharges the ground-water reservoir over most of Long Island (Cohen and others, 1968, p. 44).

The Long Island ground-water reservoir is a wedge-shaped mass of unconsolidated deposits of gravel, sand, silt, and clay. Thickness of these deposits ranges from near zero in the extreme northwestern part of the reservoir to about 600 m (2000 ft) in the south-central part and reflects the southeastward-sloping bedrock surface on which the unconsolidated deposits lie (Fig. 3). The major hydrogeologic units and their water-bearing characteristics are listed in Table 1; their structural arrangement is shown in Fig. 3.

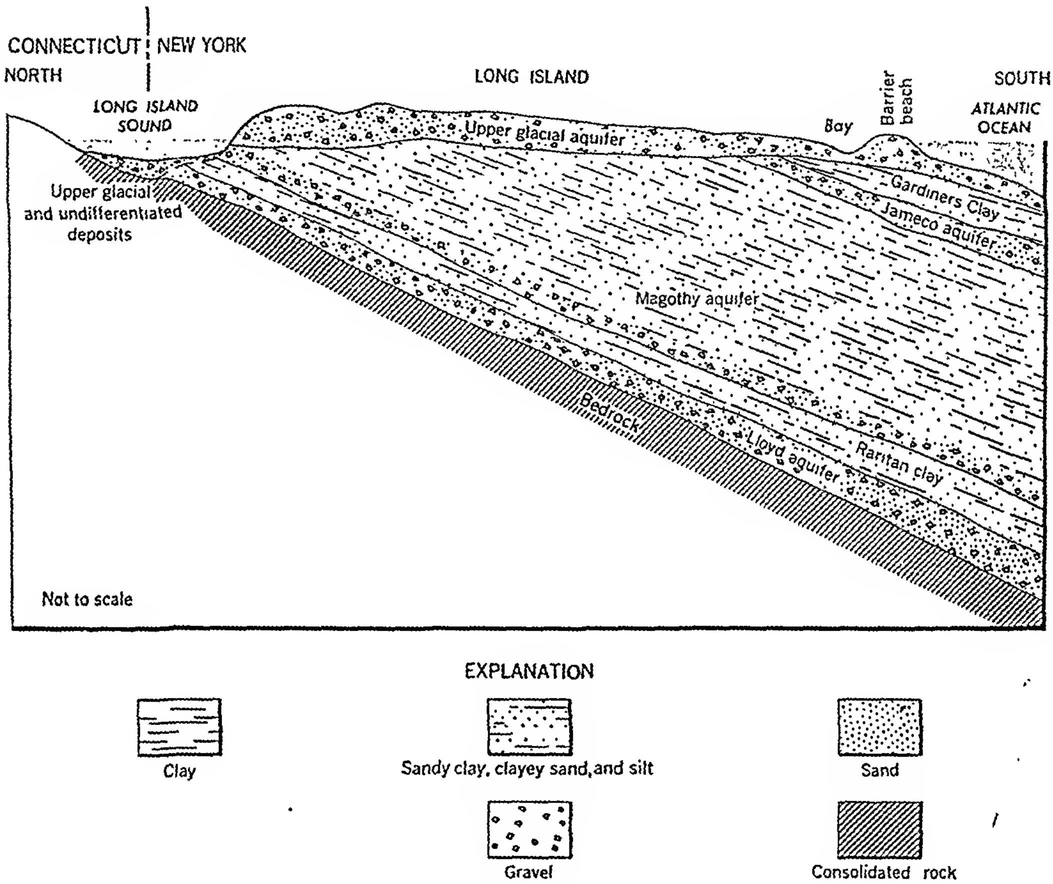

Fig. 3. Geologic features of the Long Island ground-water reservoir. (After Franke and McClymonds, 1972, fig. 8, p. F10)

The upper glacial aquifer is the shallowest of the three major aquifers. It is unconfined and is easily contaminated by wastes disposed of at or near land surface. Intermediate in position is the Magothy aquifer from which is pumped most of the ground water used on Long Island. The Magothy is unconfined to poorly confined over most of interior Long Island, and it, too, is readily contaminated, although much slower than the upper glacial aquifer. The Lloyd aquifer is the deepest. It is well confined and is comparatively well protected from contamination by surface-applied wastes by the overlying thick clay unit (Table 1 and Fig. 3).

Table 1. Major hydrogeologic units of the Long Island ground-water reservoir*

Geologic system	Hydrogeologic unit	Approximate maximum thickness (metres)	Characteristics
	Upper glacial aquifer	120	Mainly sand and gravel of moderate to high permeability; also includes clayey deposits of glacial till of low permeability.
Quaternary	Gardiners clay	35	Clay, silty clay, and a little fine sand of low to very low permeability.
	Jameco aquifer	60	Mainly medium to coarse sand of moderate to high permeability.
	Magothy aquifer	300	Coarse to find sand of moderate permeability; locally contains gravel of high permeability, and abundant silt and clay of low to very low permeability.
Cretaceous	Raritan clay	90	Clay of very low permeability; some silt and fine sand of low permeability.
	Lloyd aquifer	90	Sand and gravel of moderate permeability; some clayey material of low permeability.

* Table modified from Cohen and others (1968, p. 18).

CHANGES IN GROUND-WATER QUALITY RESULTING FROM UNPLANNED AND UNCONTROLLED RECYCLING OF WASTEWATER

The fresh uncontaminated ground water of Long Island had a remarkably low dissolved–solids concentration. The dissolved–solids concentration is estimated to have been everywhere less than 50 mg/l and in some places as low as 20 mg/l (Franke and McClymonds, 1972, p. F35). As water moved through the layers of sediment composing the ground-water reservoir, its dissolved–solids concentration changed but little because of the chemical inertness of the sediment. Representative analyses of uncontaminated water from the three principal aquifers are shown in Table 2.

For many decades after people began settling on Long Island, domestic sewage was disposed of entirely by individual cesspools. As urbanization advances eastward across

Table 2. Representative chemical analyses of uncontaminated water from the three principal aquifers on Long Island†
(Concentrations in milligrams per litre; analyses by U.S. Geological Survey)

	Aquifer		
	Upper glacial	Magothy	Lloyd
Iron (Fe)	0.01	0.61	1.5
Calcium (Ca)	1.5	0.5	0.9
Magnesium (Mg)	1.3	0.1	0.5
Sodium and potassium (Na and K)	3.8	2.7	6.7
Bicarbonate (HCO_3)	4	3	4
Sulfate (SO_4)	6	1.6	14
Chloride (Cl)	5	2.5	2.0
Nitrate (NO_3 as N)	0.02	0.02	0.02
Dissolved–solids concentration	36	15	36

† Table after Cohen and others (1968, p. 50 and 51).

Long Island, sewage systems are being constructed to dispose of municipal wastewaters from densely populated areas. Part of Kings County was sewered as far back as 1850, but regional sewering in Nassau County did not begin until about 1950 and is just now (1974) getting underway in Suffolk County. In 1972 about 7.2×10^5 m^3/day (190 Mgal/d) of mainly domestic wastewater was disposed of in Nassau and Suffolk counties through several hundred thousand cesspools and septic-tank systems and through land discharge of effluents of small sewage-treatment plants. This disposal practice, in essence, inadvertently recycles large volumes of wastewater to the ground-water reservoir in an unplanned and unregulated manner. Widespread deterioration of ground-water quality has resulted in part from this unregulated recycling, to the extent that use of the shallow aquifer as a source of potable water has been severely impaired in parts of Nassau and Suffolk counties. In a few places the intermediate aquifer has been affected similarly.

Concentration of nitrate in water from the shallow, upper glacial aquifer and to a lesser extent from the intermediate Magothy aquifer has increased many fold. In some places the concentration of nitrate is more than 20 mg/l of nitrate-N (Perlmutter and Koch, 1972, p. B229). The source of the nitrate is partly from infiltration of sewage and partly from leaching of fertilizers. Many public-supply wells in the upper glacial aquifer and a few in the Magothy aquifer have been abandoned because they yield water with a nitrate concentration exceeding the drinking-water standard of 10 mg/l as N recommended by the U.S. Public Health Service (1962).*

Other notable water-quality changes that have resulted partly from unregulated recycling of wastewater include marked increases in concentrations of dissolved solids, chloride, sulfate, sodium, and hardness. Concentrations of these parameters in the shallow ground water have increased by roughly an order of magnitude or more above their normally low primordial levels (Table 2) throughout much of Nassau County and in some parts of Suffolk County (Perlmutter and Koch, 1974; Perlmutter and Guerrera, 1970). Detergents have also been detected by many water analyses of shallow ground water. In general, either concentrations of these parameters, other than nitrate, are presently (1974) below standards for potable water recommended by the U.S. Public Health Service (1962), or no standards have been established. Although at this time no concentration standard exists for sodium, its presence in drinking water is of concern to persons suffering from cardiovascular diseases (Wolff, 1973; Salvato, 1972). "The American Heart Association's 500-mg and 100-mg per day sodium diet recommends that distilled water be used if the water supply contains more than 20 mg/l of sodium", according to Salvato (1972, p. 121). Much of the shallow water, at least in Nassau County, has a sodium concentration of more than 20 mg/l—elevated from just a few milligrams per litre in the uncontaminated ground water. Hence, its use has been somewhat impaired, on the basis of sodium concentration, in that the water can no longer be freely consumed by everyone.

PLANNED AND CONTROLLED WASTEWATER RECLAMATION AND RECYCLING THROUGH GROUND-WATER RECHARGE

As indicated earlier, public supplies account for 78% of the ground-water demand in Nassau and Suffolk counties. Industrial water needs, although 19% of the total, are not

* This standard and standards for other parameters of drinking water are mandatory for drinking water and water-supply systems used by carriers and others subject to Federal quarantine regulations.

concentrated in any locale, and agricultural demand is small. A similar pattern of demand most likely will prevail through at least the next several decades. Hence, any plan for recycling wastewater through ground-water recharge in these counties will be rigorously constrained for public-health considerations, as ground water in this area is mainly used domestically and is the only potable water available.

The land-utilization pattern in most of Nassau and Suffolk counties precludes much application of low-rate recycling schemes designed to use the soil mantle as a major element in the treatment process, as described by Sopper and Kardos (1973). Rather, the high value of land and the very permeable nature of the surficial deposits over most of the area favor recycling involving high rates of application of treated wastewater. Although high-rate recharge (several metres per week) is hydraulically feasible and is highly desirable from a land-use standpoint, little chemical quality improvement of the applied water is likely through interaction with the soil and aquifer because of the high flow rates and the chemical inertness of the aquifer materials. Therefore, wastewater must be treated to the extent that it meets many of the requirements of drinking water before it can be recycled as ground-water recharge. Removal of nitrogen is a major prerequisite.

Technology exists for purifying wastewater to stringent standards required for recycling by way of ground-water recharge or streamflow augmentation. At least four methods of nitrogen removal from wastewater have been demonstrated (Culp and Culp, 1971; Metcalf and Eddy, Inc., 1972). The methods include:

(1) Biological nitrification and denitrification.
(2) Air stripping of ammonia.
(3) Selective ion exchange of ammonium.
(4) Ammonia removal by break-point chlorination.

Depending on other requirements, one of these nitrogen-removal unit processes can be

TABLE 3. Anticipated water quality from proposed advanced waste-treatment facility in Nassau County*
(All data in milligrams per litre except where indicated)

Parameter	Concentration
Biological oxygen demand	0–2
Chemical oxygen demand	10–25
Total organic carbon	5
NH_3 as N	0–1
NO_2+NO_3 as N	0–1
Organic N	1–2
Total N	2–3
Total PO_4 as P	0.1–0.2
Turbidity (Jackson turbidity units)	0.1–1
Suspended solids	1–2
Total dissolved solids	350–500
Cl^-	70–80
SO_4^{-2}	70–90
Phenols	<.005
Methylene blue active substances	0.03–.03
Coliform (no. per 100 ml)	<2

* Table modified from Beckman and Avendt (1974, table 33).

incorporated into a combined biological and (or) physical-chemical, advanced waste-treatment process to yield reclaimed water of high purity. A treatment scheme proposed for reclamation of water from municipal sewage in Nassau County includes: (1) chemically aided primary sedimentation, (2) two-stage biological removal of carbonaceous and nitrogenous substances, (3) filtration, (4) adsorption on carbon, and (5) disinfection by chlorine (Beckman and Avendt, 1974). This process is expected to yield water having the quality characteristics shown in Table 3 and which will be recharged to the ground-water reservoir. Other somewhat different advanced waste-treatment processes are in use or in construction stage in other parts of the United States. Culp, Culp, and Hamann (1973) have reviewed some of these processes.

Concentrations of many of the dissolved inorganic constituents in reclaimed water will increase through each reuse cycle unless provision is made in the advanced waste-treatment process to remove or dilute them. The severity of these increases depends partly on the initial concentration of constituents and the use to be made of the water. For example, on Long Island the dissolved–solids concentration of the water is increased from less than 50 mg/l to roughly 400 mg/l through the first use (mainly domestic) and reclamation cycle. Considering just the dilution expected from the natural blending of reclaimed water through ground-water recharge with the natural recharge from precipitation, the dissolved–solids concentration might not significantly exceed the U.S. Public Health Service (1962) potable-water standard of 500 mg/l until after the third cycle. In contrast, in Orange County, California, where dissolved–solids concentrations approach or exceed the potable-water standard initially and dilution from natural recharge is low, water reclaimed after the first cycle has a dissolved–solids concentration of 1100 mg/l and is diluted with desalted seawater before being recharged (Cofer, 1972).

Various experimental and demonstration projects involving wastewater reclamation and ground-water recharge are underway on Long Island. These include low-rate (5 cm per week) spray irrigation of primary-treated sewage, high-rate (several metres per week) basin recharge of highly treated wastewater, and well injection of highly treated wastewater. Each method has favorable aspects as well as drawbacks, but all seem to be technically practical. Basin recharge of water reclaimed from sewage is probably the most practicable method of recycling wastewater throughout most parts of Long Island.

In conclusion, controlled recycling of wastewater through ground-water recharge will not necessarily prevent all water-quality deterioration. Rather, it is a means of conserving water and partly managing the deterioration within various economic and public-health constraints.

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RECYCLING AND WATER QUALITY

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Abstract. The growing demands on the limited water supply of the world may be related directly to pressures created by an expanding global population and the consequent broadening industrial base and intensified agriculture. Wastes from these sources have degraded water quality and compound the problem of acceptable supply versus increasing demand.

Evaluation of water-resources data in choosing the best courses of action consistent with judicious use and protection of the available water supply, has resulted in increased emphasis on recycling water. To fully assess the effects of recycling on water quality, for whatever water use, hydrologists will be obliged to consider the entire interdependent hydrologic system and to gather and evaluate truly comprehensive data.

INTRODUCTION

The world's water supply has practically neither diminished nor increased since the earth's atmosphere was formed hundreds of millions of years ago. While water use continues to escalate in response to the expanding world population which is expected to double in the next 35 years, the total amount of water available remains about the same. Increases in population result in increased use of water for urban areas, factories, farms, and power plants, as they, in turn, respond to needs and demands of people. Thus, the relation of supply to meet demand is strained in the direction of greater demand.

Uneven distribution of water resources has long been recognized. This fact, plus droughts experienced in this and other recent decades, have prompted increases in recycling and brought about a more general awareness of the potential benefits of reuse. The issue of water reuse has largely been avoided (Graeser, 1974), although it is known that some major cities around the world already withdraw river water that contains a high percentage of sewage effluent for treatment as public water supplies (Culp *et al.*, 1973). Numerous published reports attest to successful spray irrigation of sewage effluents which stimulates crop production. Land spreading is used to dispose of wastes and, at the same time, to help reclaim poor and despoiled areas and to upgrade others. Artificial recharge of aquifer systems for water supply and as buffers against salt-water intrusion is becoming more common. Thus, it would seem that there is no longer the question of whether we should recycle, but rather how and when should it be done, particularly in water-short areas where action is demanded.

Accepting the premise that recycling of water will be practiced more widely than before reinforces the need to monitor the quality of water to be recycled and the water with which it might come into contact in order to evaluate the immediate impact of reusing water and to estimate long-term subtle effects. If warranted, expeditious alternative action could be

taken, and recycling schemes and techniques could be modified according to results of comprehensive monitoring. Conversely, decisions already made could be further supported by these same data.

Wastes from man, agriculture to sustain his life, and goods and services to ease his way as affluence will permit, ultimately contact an aquatic environment. Potential contaminants are as various as all known inorganic and organic elements and compounds, which now number several million, and all those to come, and all the unknown. The variety grows by the formulation of approximately 10,000 new compounds each year.

Water is close to being a universal solvent and is an extremely efficient transport mechanism. Fluvial sediments, either organic or mineral, are also efficient transporters. Biological transformations of materials in solution, sorbed on sediments, or in the form of organochelates are controls on water quality to be reckoned with. As hydrologists and water managers evaluate data and advise others who must make decisions concerning sufficient quantity of water of acceptable quality, it is incumbent upon all involved to understand these controls and their reactions with and dependence upon each other, and the relation of the composite of the controls with the environmental setting. For this understanding, really comprehensive data of good quality are necessary.

The best-managed water systems require the investment of considerable time by talented managers guided by properly evaluated data of good quality. Such management defines problems, seeks improvement, and decides how best to shape the future instead of being shaped by it. The purpose of this paper is to draw attention to the current manner of evaluating water quality, how recycling may affect such an evaluation, and to outline the elements of a comprehensive, interdependent evaluation.

WATER RESOURCES ASSESSMENT

Water quality must be considered as only one of several elements that bear upon water as a resource. Quality has a proper and important place, which is no greater nor less than the quantity of water available, natural controls, man's influence, intended water use, and acceptability of the water for use by man. Some of the more important elements to be considered are given in Table 1 in an arbitrary ranking. Location, climate, and land slope are major controls. Surficial and subsurface minerals are sources of solutes for both surface water and ground water. Land use in an area under investigation is now commonly defined early in the study because it bears considerably upon the amount of runoff, infiltration rates, and point and diffuse sources of effluents and soluble materials.

These factors are largely responsible for the quantity and quality of water available; however, an assessment of water resources would not be complete without more definitive information on the amount of surface water and ground water available and detailed knowledge of the quality of both. A bountiful supply unacceptable for intended use without prohibitively expensive treatment satisfies little or none of world thirst. On the other hand, there may be numerous uses for which a poorer quality of water would be perfectly acceptable. Thus, considering quantity and quality of water as equal elements of assessment seems obligatory to the hydrologist.

Water use and reuse has much to do with assessment. Recent reports (Graeser, 1974; Bruvold and Ongerth, 1974) indicate that the public will presently accept a limited amount of reclaimed water, primarily for low-contact uses. Use of such water for drinking, food preparation, and bathing was acceptable to slightly less than 50% of the people interviewed.

TABLE 1. Elements of a water resources assessment

Topography	Availability of water
Hydrology	Quality of water
Geology	Water use
Land use	Socio-economic factors

Little is known about acceptability of reclaimed water from sources other than sewage effluents; however, salt loads from irrigation returns are known to be troublesome without costly treatment or dilution with fresh water. Cooling-water returns from industry and power generation have been described as both deleterious and beneficial. Acceptability is ill-defined where metals are transported from mining areas and pesticide residues move about in solution or sorbed on fluvial sediments. It would seem that social constraints on water use and reuse, and the economics of clean or acceptable water, on the other hand, are strong factors in assessing water resources, but indeed, the deciding factor may be and often is cost alone.

WATER-QUALITY ASSESSMENT

Historically, only selected elements of water-quality assessments have been measured. And these elements have been evaluated as if they were independent entities. Recognition is growing, however, that only comprehensive data such as those summarized in Table 2, when properly integrated, contribute to an undistorted water-quality assessment. Whether unstable water properties are measured *in situ* or samples are collected for analysis in the laboratory, representative sampling is prerequisite to obtaining valid data. There is little justification in analyzing poorly collected or poorly preserved samples that may lead to biased interpretations. Thus, the validity of data may be directly related to the confidence in sampling.

TABLE 2. Elements of a water-quality assessment

Characteristics	Hydrologic component
Inorganic	Solution
Organic	Suspension
Biological	Bottom material
Sediment	Aquifer material
Physical	

Complementing field measurements, determinations in a laboratory with a high degree of analytical competence where quality control is maintained are equally essential in providing valid data. Capability is needed for measurements of physical, chemical, and biological characteristics in all components of the aqueous system.

Virgin water quality is closely related to lithology and contact time; however, controls

on quality are commonly biological and organic. Because carbon is essential to all forms of life, it is used by biological populations whose rates of carbon assimilation are determined in large measure by temperature and sunlight. Inorganic materials are bound within the bio-organic complex in addition to being present as solutes. Sediment may be a source or a sink for many substances, including pesticides, heavy metals, and nutrients. Above all, sediment may be an excellent historical integrator, and chemical analysis of sediment samples in conjunction with measurement of sediment discharge quickly reveals much about a drainage basin.

Substances that need to be assessed in an effective water-quality assessment may be found in true solution, associated and transported with suspended material, or sorbed on fluvial material of today which becomes the bottom material of tomorrow when stream energy has dissipated and particles have settled out.

When studying the quality of water withdrawn from aquifers, the characteristics to be measured are similar to those for surface water, but, in addition, knowledge of the physical and chemical properties of the aquifer material is essential in understanding the liquid phase.

Thus, briefly, a case is made for collection of really comprehensive data. Current technology is adequate to permit all measurements needed. So, it is emphasized that to selectively ignore any characteristic in any component of the aqueous system may lead to a grossly erroneous assessment.

EVALUATING WATER QUALITY

With truly comprehensive and valid data available, one may begin to evaluate water quality. A checklist and pertinent factors are given in Table 3.

TABLE 3. Factors for evaluating water quality

Representative sample paramount
Validity of data=confidence in sampling
Validity of data=analytical competence
Consideration of natural controls
Consideration of man's influence
Consideration of use criteria
Evaluation of comprehensive data as an interdependent system

Water quality is the end product of many elements having numerous controls, and the individual values of measured elements are complementary to and highly dependent upon one another. Therefore, it is essential that all the water-quality elements in all the aqueous components be examined with their interdependence in mind for a meaningful water-quality evaluation. Natural environmental controls will be considered in relation to certain land-use practices and resultant point and diffuse contamination.

Once quality is defined, suitability of the water for an intended use remains to be judged. Criteria for use are even more variable than uses themselves. Criteria for a public water

supply may revolve around health. Industrial requirements vary from the need for almost pure water to water in which solutes are of little concern—cooling water, for example. Agricultural criteria lie somewhere between those of public supplies and those of industry if certain elements injurious to plants are not present. On the other hand, high nutrient loading would be welcome.

Water selected for reuse is likewise to be judged by use criteria. Recycling can take many forms, from spray irrigation of sewage effluents to aquifer injection of water for drinking-water supplies. The same water-quality elements measured in the same aqueous components, as outlined for a general assessment, is equally useful in evaluating reuse suitability.

SUMMARY

One means of assessing whether a course of action is indeed judicious, is the amount of time and effort expended by talented and knowledgeable people in the decision-making process. To be preoccupied with current problems and to devote little or no time to planning for the future inevitably makes it more difficult to resolve the problems of acceptable water supply versus an ever-increasing demand. Evidence is accumulating that long-range plans to increase reuse of water are receiving wider attention and that public acceptance of the practice is becoming more favorable.

Although a water-quality evaluation involves consideration of several factors as an interdependent system, adequate technology needed for measurement and evaluation is generally available. But as recycling is practiced more intensely, it will become more incumbent upon hydrologists to gather the truly comprehensive data necessary for undistorted assessment.

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VARIOUS LAND ADAPTATIONS TO FOOD WASTEWATER TREATMENT

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Abstract. Campbell Soup Company has adopted a philosophy that where food-processing plants can be located in rural areas, attempts should be made to utilize the natural environment for treatment purposes. If utilized properly, the land can provide us with an enormously effective way to treat and dispose of our wastewaters. Two examples of proper utilization of the environment are Campbell's plants at Sumter, South Carolina, and Paris, Texas. Both systems are the spray irrigation technique of treating their wastewaters.

The Sumter system can be classified as following the "conventional" technique of spraying wastewater onto sandy soils with high infiltration capacities, and allowing the water to filter down through the soil. One added feature, however, is the inclusion of a network of perforated drainage pipe 5 to 7 feet underground to improve the infiltration capacity of the soil and drain off the treated wastewater.

The Paris system is an "overland flow" surface filtration system which is constructed on land that is relatively impervious and which will not permit high infiltration rates. This is a relatively new, but highly effective, concept of spray irrigation wherein the wastewater is spread in a thin sheet to have a good interaction zone with soil humus.

Both the Sumter and Paris systems have proved to be extremely efficient, each removing greater than 98% of the applied BOD for approximately 10 years. Experience with systems like Sumter and Paris has led us to believe that more attention should be focused on the land and its proper management.

INTRODUCTION

Although we generally do not associate them as such, Nature creates many different kinds of wastes. Except for major catastrophes such as earthquakes and flooding, these natural wastes are rarely ever noticed by the casual observer. This is so because Nature uses her own resources to eliminate waste products. For example, each fall, tons of organic litter from dying vegetation are dropped on the soil surface, but yet the land does not choke on its own refuse. It has, rather, the enormous capability to accept this litter and provide the conditions for these wastes to decay naturally without detrimentally affecting the surrounding environment.

For many years man, too, has used the land for disposal of his wastes. There are too many instances, however, where man has attempted to use the land without giving much forethought to the whys and hows of proper utilization. We know that the land is capable of utilizing organic wastes and converting them to plant nutrients and other innocuous substances. If we can learn how to make the optimum use of our available lands, we will find that Nature will lend a great deal of assistance in treating and disposing of our wastes.

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At Campbell Soup Company we have adopted the philosophy that where food-processing plants can be located in rural areas, attempts should be made to utilize the natural environment for treatment purposes. Two perfect examples of this philosophy are the plants located in Sumter, South Carolina, and Paris, Texas. This paper will describe how, in each case, the existing local environments were utilized and converted into wastewater treatment systems capable of achieving extremely high degrees of efficiency.

The Sumter, South Carolina, plant consists of one of the world's most modern, integrated poultry operations. At this plant, live poultry is completely processed under the most sanitary conditions to provide meat for Swanson Frozen Dinners and for Campbell's Soups. The Paris, Texas, plant processes the complete line of Campbell's Soups along with bean and spaghetti products.

SELECTION OF THE TREATMENT SYSTEM

Spray Irrigation Versus Conventional Treatment

As is the case when any new plant is built, the site selection must be considerate of the type of wastewater generated by the plant and the treatment options available. Many food-processing plants, but certainly not all, are located in rural or semi-rural areas. This can create some very definite problems from a wastewater treatment standpoint. For example, the closest municipal system may be located too far away to tie into it, or it may already be at or above design capacity and could not accept any additional waste. On the other hand, however, rural locations many times do possess the luxury of land availability at reasonable cost, which in turn, allows the plant to consider a wide variety of treatment alternatives.

Campbell Soup Company has found through experience that, if enough land is available for the use of the spray irrigation technique of wastewater treatment, it should be given high consideration. Spray irrigation is capable of consistently producing a higher-quality effluent than conventional secondary treatment systems and at a cost which is highly competitive with these other methods.

Both the Sumter and Paris plants are located in semi-rural areas where, all factors considered, it appeared that spray irrigation was the most practical treatment option to take. There is one very significant difference between these two treatment systems, however. Whereas the Sumter system can be generally thought of as a somewhat "conventional" spray irrigation system where the applied wastewater percolates into the ground, the Paris system is built on a clay soil with little infiltration and utilizes the "overland flow" technique.

Spray Irrigation Via Infiltration

At Sumter, South Carolina, the plant site consisted chiefly of sandy soil with a relatively high infiltration rate. Upon further investigation, however, it was found that the sandy soil was underlain with a dense clay subsoil which began between 5 and 7 feet below the surface.

It appeared that the site would be an ideal one for the use of the spray irrigation form of waste treatment if a way could be found to overcome the infiltration barrier presented by the clay subsoil. Although the surface infiltration capacity of the sandy soil was extremely

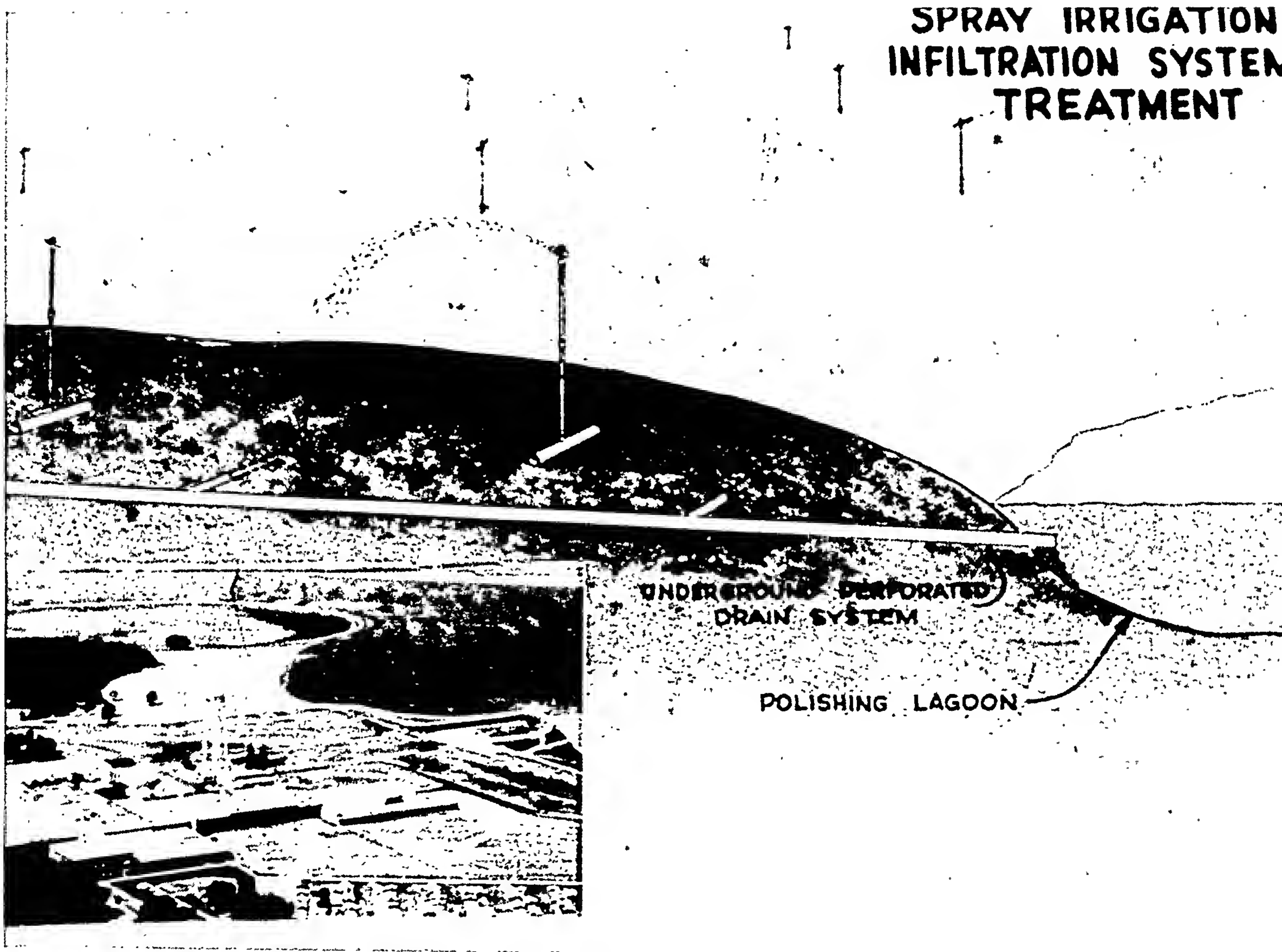


Fig. 1 This modern plant at Sumter, South Carolina, produces Swanson frozen dinners and poultry meat for Campbell's Soups. By adapting to nature's ways and carefully utilizing and managing the environment, Campbell has demonstrated that it is possible to treat waste while encouraging an abundance of wildlife. The waste treatment system here is capable of handling peak flows of three million gallons per day, yet it is compatible with the many small streams which criss-cross the area and which local residents are dependent upon for extensive hunting and fishing.

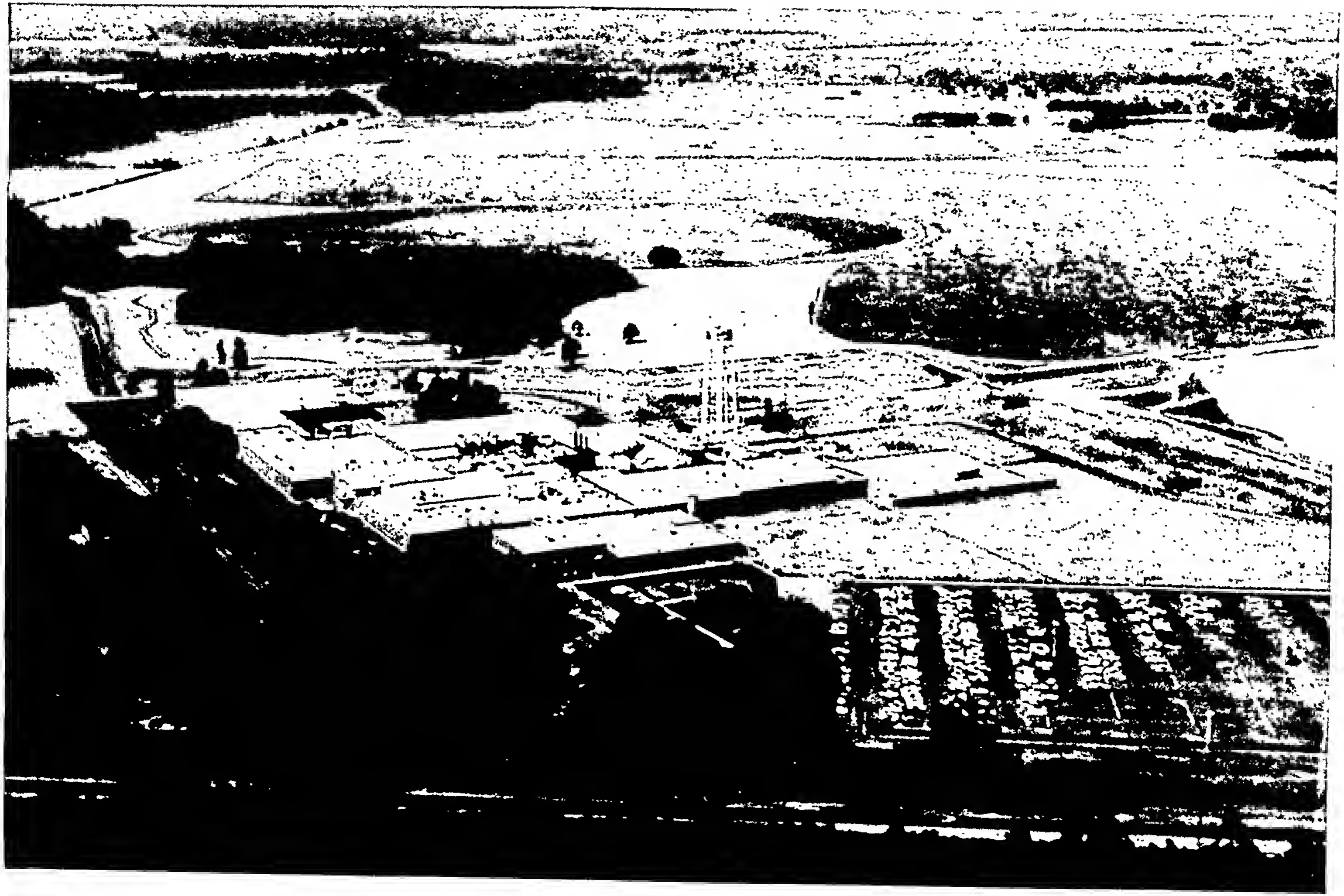


Fig. 2 Air Photograph of Sumter Plant.

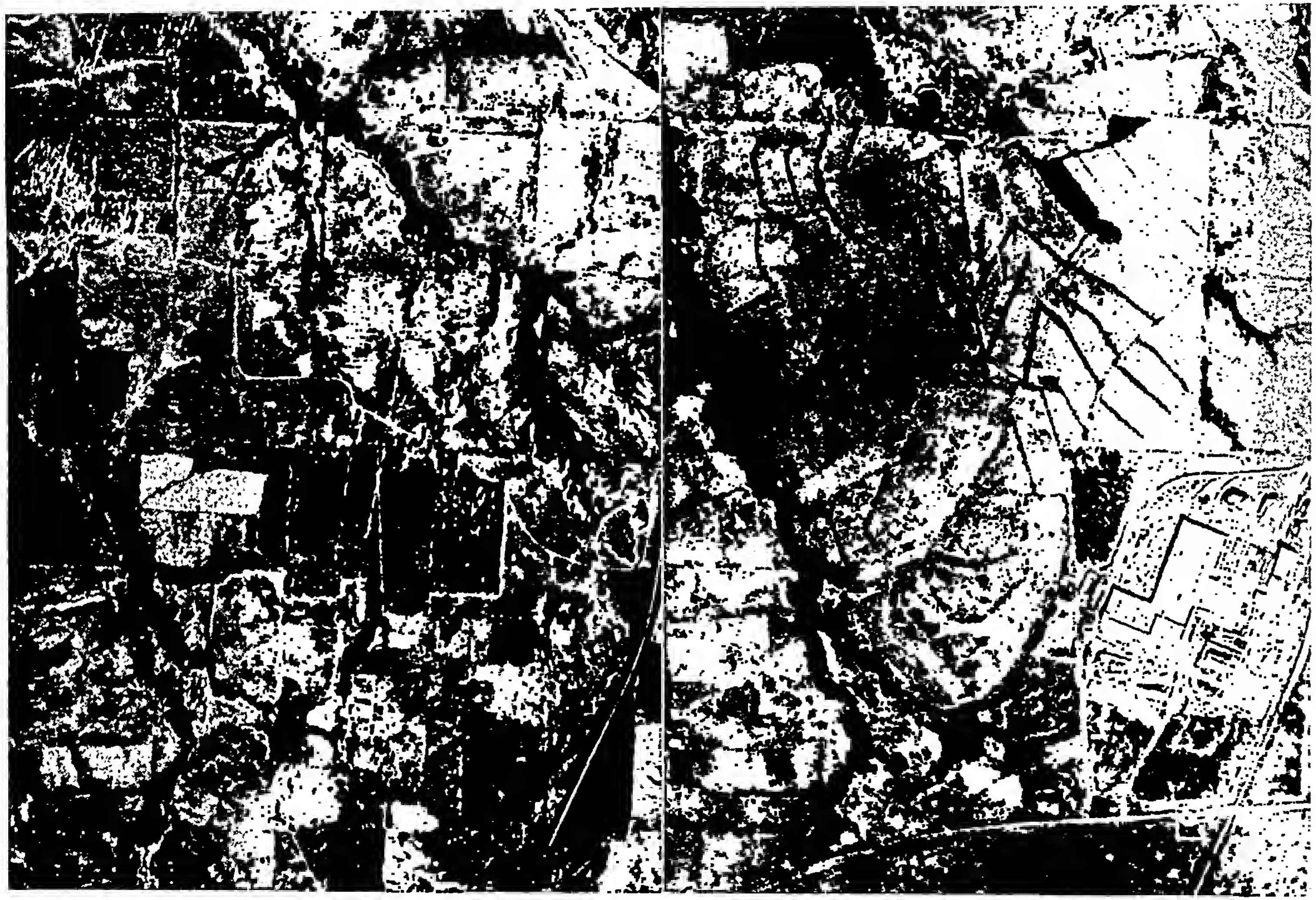
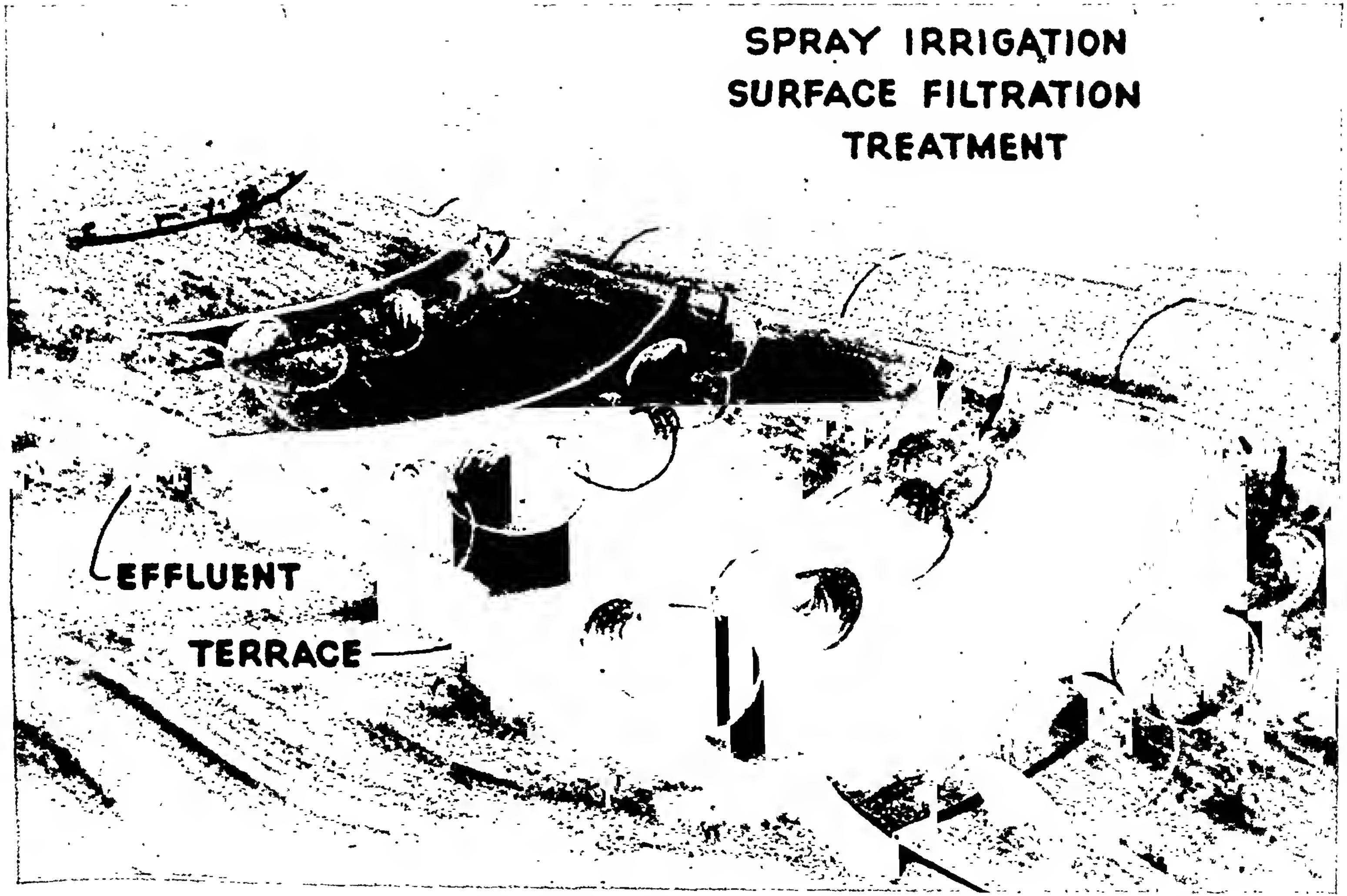


Fig. 3


SPRAY IRRIGATION
SURFACE FILTRATION
TREATMENT
EFFLUENT
TERRACE

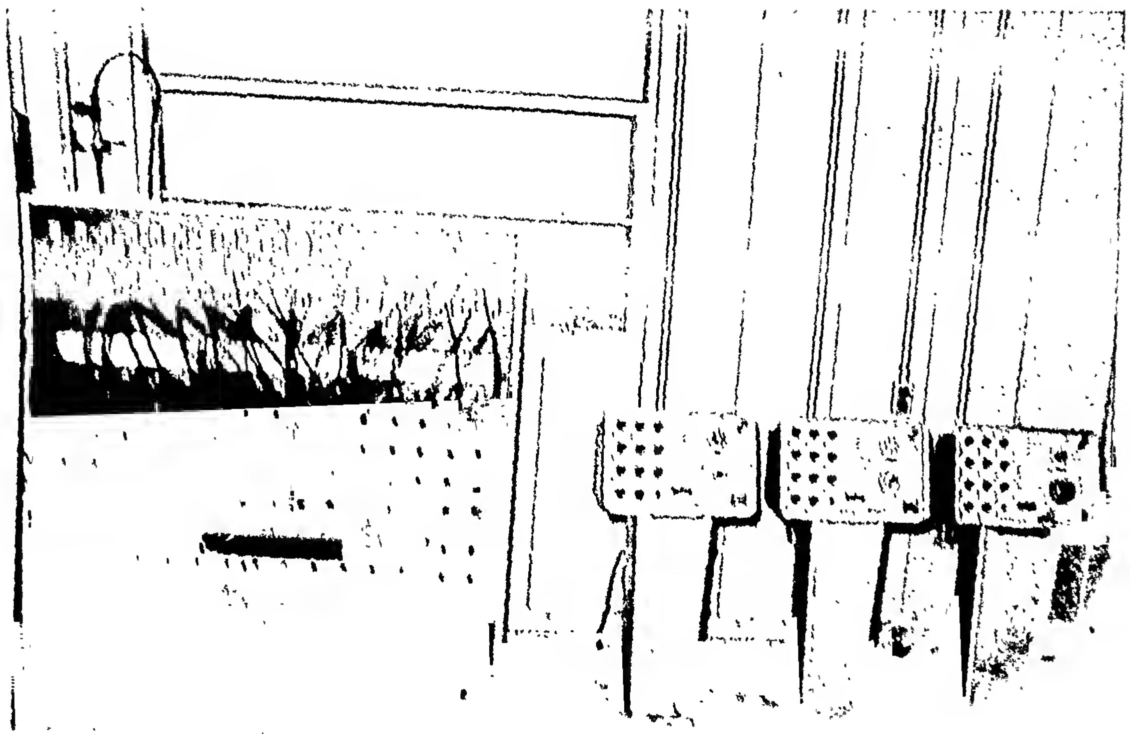


Fig. 6 Spray Irrigation Control Station.

high, the clay subsoil was sufficiently dense so that downward water movement would be severely impeded. If the normal spray irrigation application rates were used, the fields would become flooded.

To overcome this problem, approximately 200 acres were covered with a drainage system consisting of a network of perforated drainage pipes buried so that they were just above the clay subsoil. This improved the already good infiltration capacity of the sandy soil, but, most importantly, it provided a means for conducting water away from the field after it had passed through the 5 to 7 feet of sandy soil.

Although most of the treatment site was quite flat, a natural depression (known locally as a Carolina Bay or savannah) covered part of the area. Again, adapting the system to the natural conditions, the savannah was converted into a pond by directing the drainage pipes into the depression, as shown schematically in Fig. 1. Since the savannah was a natural depression, very little construction was necessary to convert it into a pond. Some areas were regraded to eliminate uneven depths and to form uniform side slopes. An overflow-type pipe drain was added to maintain a 4- to 5-foot pond depth. The pond covers an area of roughly 45 acres. Due to physical limitations, approximately one-third of the spray network does not drain into the savannah, but rather into a receiving stream. Figure 2 shows the Sumter plant and its wastewater system, including the polishing pond.

Overland Flow Spray Irrigation

In a unique departure from the conventional spray irrigation disposal system, the wastewater generated by the Paris, Texas, plant is treated by the overland flow process. This technique is a highly effective substitute for conventional spray irrigation when the characteristics of the soil limit the downward movement of applied water. Most of the Paris soil is grey clay loam overlying a red clay subsoil. The infiltration rate is on the order of 0.10 inches per day and the runoff factor is extremely high.

Soil of the Paris type is suitable only for grassland farming, but during the first third of this century, it was used for raising cotton. Improper soil management led to severe sheet and gully erosion and finally to the abandonment of the land sometime around 1940. When the land was acquired in 1960, most of the topsoil had been stripped away, much of the area was covered with brush and small trees, and the old erosion gullies had cut deeply into the red clay subsoil. Using heavy earth-moving equipment, the erosion features were eliminated and a network of slopes and terraces developed and planted to grass. The before and after pictures in Fig. 3 show how the severely eroded soil caused by the mismanaged cotton farming was reconstructed and rehabilitated to form uniform slopes and terraces for treatment purposes, thus becoming an outstanding example of soil conservation.

The spray irrigation disposal system in Paris is one of perhaps less than a dozen overland flow systems in the country which have been deliberately designed and installed on an area of impervious soil. As shown in Fig. 4, wastewater is applied along the top of a carefully prepared slope and becomes purified by flowing through the vegetative litter on the soil surface and is collected in a collection terrace at the bottom of the slope. Since the only significant water loss is through evapotranspiration, it follows that this technique is exceptionally well adapted for the collection and reuse of treated water. It is also evident that the overland flow method of treatment can be used in areas where an impervious soil or a high water table would have ruled out the possibility of conventional spray irrigation that normally relies upon infiltration.

DESCRIPTION OF THE SUMTER SYSTEM

Pretreatment

Figure 5 is a schematic flow diagram showing the origin of various wastewater flows and the methods of treatment. Blood, feathers, and offal are all handled in separate piping systems. The feathers and offal go through separate sets of fine -meshrotating drum screens. These screened effluents then combine with each other and with the floor drains from the general plant drainage systems. The combined effluents then pass through a coarse screening system and into a vacuum flotation system for the removal of grease and settleable solids. The liquid effluent from the vacuator passes through two rotary disc screens before dropping into a 50,000-gallon storage reservoir from which it is pumped via turbine pumps to the spray irrigation system. All solids—feathers, offal, grease and settleable solids—are trucked to a rendering operation for the preparation of feed.

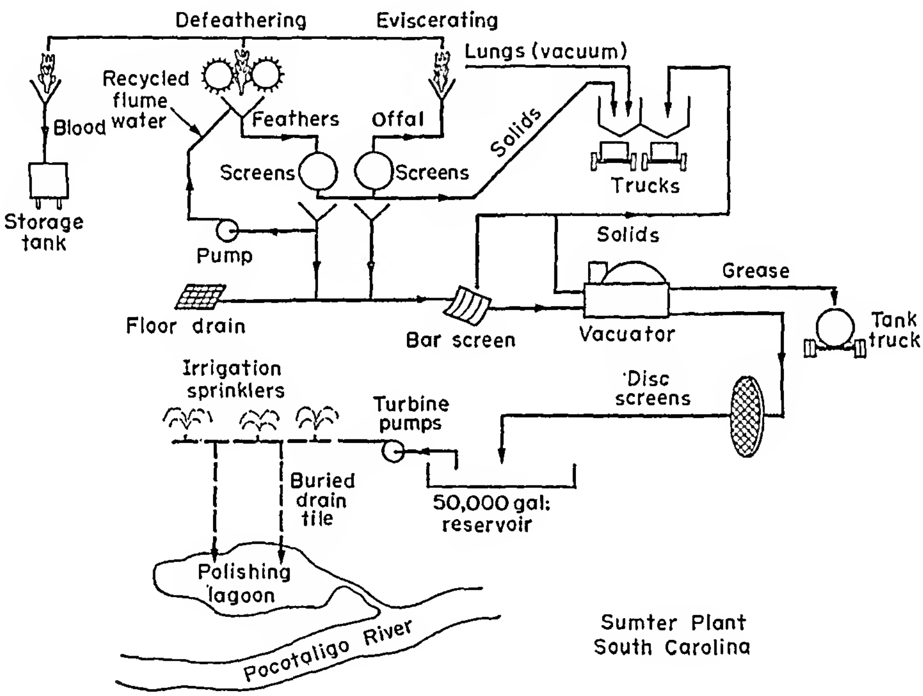


Fig. 5

Spray Irrigation

The wastewater distribution network in the spray irrigation system consists of buried asbestos-cement and plastic pipe. The 6-inch to 12-inch main lines are asbestos-cement, while the 4-inch to 2-inch lateral lines are PVC plastic pipe. Steel riser pipes project above ground from the plastic pipe and support sprinklers about 4 feet above ground. There is a total of over 600 sprinklers with a discharge rating of between 20 and 30 gallons per minute at 60 psi. There are eighty-three lateral sprinkler lines, each equipped with an automatic valve which is operated by air from a plastic air tube originating at the control center.

The entire spray irrigation system is fully automated. A liquid level control system in the 50,000-gallon reservoir activates the turbine pumps as the water level in the reservoir rises. Figure 6 shows three automatic programmers which are connected to the pump starting circuits. As each pump starts, it energizes a clock timer in one of the programmers. This, in turn, opens the valves in the spray field that are programmed to that pump. With the use of an air compressor, air is pumped through plastic tubes to the valves in the field. To open the valves, the programmer automatically releases the air pressure to the valves.

When a sprinkling cycle for one group of lines has been completed, the programmer automatically advances to a different group of sprinkler lines and so on until the lines have all received their predetermined allotment of water. The plug board with the plastic air tubing shown on the left provides for convenient regrouping of lines as field conditions or harvest schedule dictates.

Hydraulic Effects on Groundwater*

Although it was expected that the underdrainage pipe system would transport much of the wastewater away from the field and into the pond, it was uncertain as to just how effective the transport system would be. Therefore, in 1970 and 1971, studies were conducted to trace the rate of the applied wastewater, and to determine the hydraulic effects that the spraying of large quantities of wastewater might have on the groundwater system of the area.

Before the installation of any groundwater observation wells, preliminary test drillings were made to obtain basic information on the characteristics of the soil profile and to determine the depths of installation for the observation wells. The drilling samples were

Depth sampled (FT)	Moisture content (%)	Sand (%)	Silt (%)	Clay (%)	Drilling notes
1	6.8	58	12	30	Sandy
2	5.3	60	14	26	Sandy
4	6.9	86	4	10	Sandy
6	13.0	76	4	20	Sandy clay, heavier with depth
8	16.4	72	6	22	Heavier, harder to drill, sandy clay,
10	17.2	76	4	20	dark red color with mottles of
12	17.2	72	4	24	gray clay
14	16.2	72	4	24	Less clay, reddish color
16	16.1	70	6	24	Lighter, less clay, reddish color
18	15.4	76	2	22	
20	14.6	80	2	18	More sand, more gray coloring
22	13.4	82	4	14	
24	9.0	92	2	6	
26	11.3	88	2	10	Sand
28	17.0*	94	2	4	
30	22.7*	92	2	6	

* Saturated in place. Some water probably lost in sampling.

Fig. 7. Profile data for well D2

* See Acknowledgment.

analyzed for moisture content, as well as for sand, silt, and clay content. The results of a typical drilling analysis are presented in Fig. 7. These data are similar to the average soil profile which was found in the original site investigation work.

Six groundwater observation wells were installed as shown on Fig. 8. Two wells (identified as D1 and D2) were drilled to the permanent water table which was determined to be 32 feet below the ground surface. One well was located 10 feet from the outer limit of the underdrainage system while the other was 110 feet away from the drainage network. Four shallow wells were installed to observe possible perched water table conditions. These wells were only about 9½ feet deep. Two of the shallow wells (S1 and S2) were installed at the same distances from the drainage system as the two deeper wells. The other two shallow wells were installed between two drainage lines, one well (S3) being only 10 feet from a drainage line and the other (S4) half-way between two drainage lines, or about 100 feet from a drainage line.

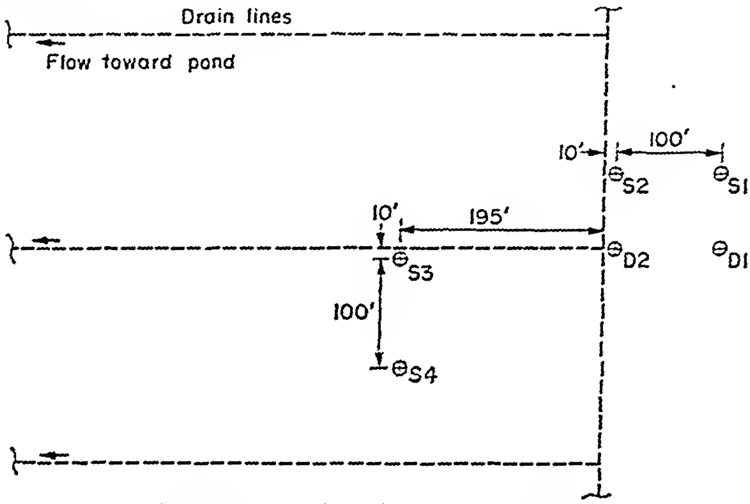


Figure 8. Location of Observation Wells

Each observation well was provided with a 3-inch PVC pipe casing tipped with a 1¼ inch by 18-inch brass screen well point. Stevens Type F water level recorders were installed and operated for a period of approximately one year.

In discussing the findings of the hydraulic investigations, it should be noted that during the 1-year study period the rainfall was about 9 inches above normal. Therefore lower, and possibly even higher water levels than those observed probably do occur at various times. The permanent water table seasonally fluctuated about 2.5 feet within a depth of between 26 and 28 feet, and was found to be responsive quite rapidly to heavy rainfalls.

During a 2-week period of plant shutdown in August, the water table was observed to drop approximately 0.75 feet. Following the plant start-up, the water table experienced a lesser but still noticeable rise. This indicates that the treatment system does contribute significant quantities of water to the groundwater reservoir. Continuously higher water level readings in well D1 versus D2 also indicate that the water table slopes towards the disposal field and savannah.

The shallow observation wells showed a perched water table which is presumably due to the relatively tight soil zone present between 6 and 14 feet below the ground surface. On many occasions this perched water could not be related to precipitation and it is assumed to be the result of heavy applications of wastewater.

DESCRIPTION OF THE PARIS SYSTEM

Physical Characteristics

The effluent arrives at the waste-treatment building from two sources within the factory. The first, containing grease from the cooking area, passes through a gravity grease separator. It then joins the stream from the vegetable washing area and the combined flow passes through 10-mesh screens to remove large pieces of solids. From here the water is pumped to the disposal field at high pressure.

The treatment system consists of some 30,000 feet of underground force main, 50,000 feet of portable aluminum irrigation pipe above ground, the 180,000 feet of control tubing in the ground operating seventy-seven pneumatically controlled valves. There are over 700 sprinklers in the system varying in size from 14 gal/min to 30 gal/min depending upon the particular treatment capabilities of the individual slopes on which they are located. The entire system is controlled automatically. Three clock timers similar to the Sumter system are connected electrically to each of five high-pressure pumps.

Prior to initial operation, the heavy clay soil on the 500-acre tract was remolded to form watersheds of 2 to 10 acres each, depending upon the lay of the land and the natural watercourses. Each watershed is from 200 to 300 feet wide and pitched towards a collecting terrace at the foot of each slope. The land was then land-planed to smoothness and planted to water-tolerant grasses. Near the top of the slope, irrigation sprinkler lines run parallel to the collection terrace at the bottom. Wastewater from the factory is discharged from the sprinklers and flows slowly downhill in a thin sheet, becoming purified en route through microbiological activity. The purified water is then collected at the terrace and flows to the receiving stream via a prepared waterway. It has been found that the pitch of individual slopes should be no less than 2% and no more than 6%. Flat slopes tend to encourage ponding while steep slopes limit retention time and encourage erosion.

Hydrological Aspects*

H-type flumes were installed at the outfall of various watersheds in the Paris system and equipped with instruments to record the water depth. A complete water balance was obtained from the known quantity of water being applied and measurement of runoff, spray evaporation, evapotranspiration and deep soil percolation. The water data are believed

TABLE 1. Hydrology of the overland flow treatment system

	Water applied, %		Water accounted for, %		
Season	Spray	Rainfall	Evaporative losses	Runoff	Deep-soil percolation
Spring	76	24	23	56	21
Summer	86	14	28	55	17
Fall	73	27	13	64	23
Winter	63	37	10	68	22
Annual	74	26	18	61	21

* See Acknowledgment.

accurate to plus or minus 10%. Water balance measurements accounted for 93% of the total liquid applied, runoff measurements accounted for about 61%, and the remaining 21% percolated through the soil. Table 1 summarizes the hydrological data for the area studied.

MECHANICS OF TREATMENT

Plant Cover

Due to the relatively heavy application rates of wastewater in both the Sumter and Paris systems, only water-tolerant grasses will grow in the spray irrigation areas. The grass serves a multi-purpose function. First, it protects the soil surface from erosion and, in the overland flow systems, retards the flow of water across the slope. Next, it provides a protected habitat for microorganisms to grow and a vast surface area for adsorption of impurities contained in the wastewater. Finally, when cut for hay, it is a valuable cash crop and provides an effective means for reclaiming nutrients which are released in soluble form when the organic waste material decomposes. Both the Sumter and Paris systems consist of Reed Canary grass. Analysis of this grass has shown the mineral content to be higher than normal good-quality hay and the concentrations of nitrogen—crude protein values ranged up to 23%—and phosphorus are nearly double their published values. Such grass, therefore, would appear to make an excellent food source for animals in addition to being a valuable method of reducing the nutrient concentration in the wastewater.

Biological Factors

The spray irrigation technique is dependent almost exclusively on microorganisms living in the soil and on the plant surfaces for the degradation of organic substances. The types

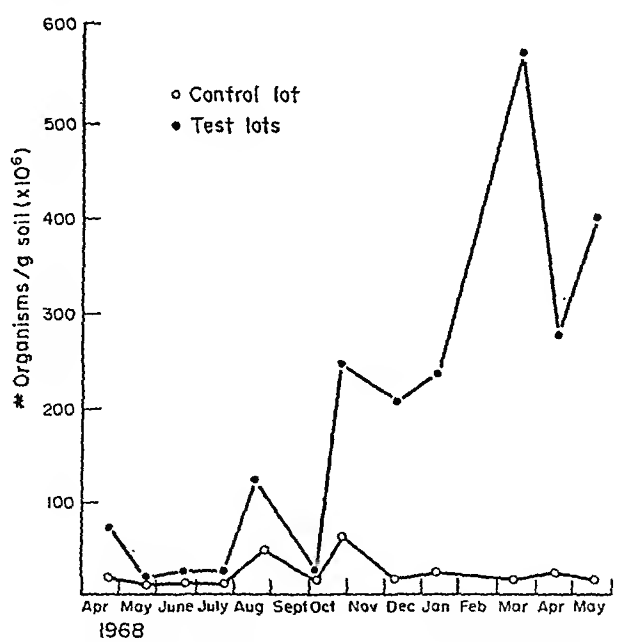


Fig. 9. Total Microbial Population on Control and Test lots

of organisms are no different from those found in local soils not under wastewater irrigation. However, the oxidative activity of organisms in the spray fields is far greater than those not under irrigation. This tends to indicate the presence of some type of seeding process whereby microbes specific for the wastewater develop on the treatment site.

It has long been recognized that a spray irrigation system will continue to purify water when temperatures drop to near freezing. Biological studies have shown that, although the respiration of microorganisms decreases as temperature decreases, the number of organisms actually increases with falling temperatures, thereby maintaining a constant level of mass activity. Figure 9 shows the results of a study designed to demonstrate the changes in microbial population on the spray fields caused by seasonal temperature fluctuations.

Buffering Capacity

Spray irrigation systems generally have the outstanding capability of handling shock loads on the one hand and periods of long shutdown and immediate start-up on the other, producing excellent results in either case. In addition, wide variations in effluent character, such as occur during night cleanup, produce no adverse effects. This is shown in Fig. 10 where the conductivity of the untreated wastewater fluctuates widely, but the conductivity of the final effluent remains fairly constant at all times. In the infiltration-type systems the grasses, and especially the soil, provide this high buffering capacity. In the overland flow systems, if a single terraced slope is accidentally overloaded or suffers a mechanical failure, treatment continues in the long runoff terraces and waterway before the effluent reaches the receiving stream. In other words, a great deal of "fail-safe" capacity is naturally built into the system.

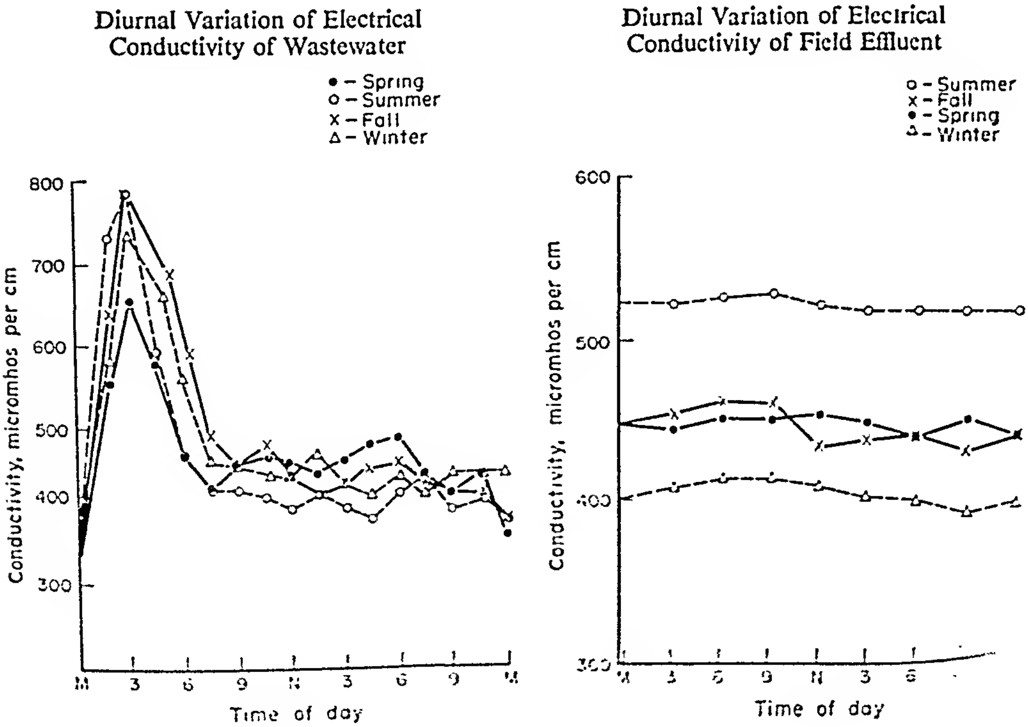


Fig. 10

TREATMENT EFFICIENCY

Sumter Plant

The efficiency of the Sumter system has been excellent. The biochemical oxygen demand of the raw wastewater averages approximately 600 mg/l while the final effluent averages 10 mg/l, an efficiency greater than 98%. Since a great deal of the treated wastewater flows into the groundwater reservoir, the amount of water actually leaving the plant property via an overground route is only a fraction of the raw wastewater volume. It is estimated that the surface runoff to the receiving stream varies somewhere between 10 and 40% of the applied flow.

Assuming a plant discharge of 4 million gallons of wastewater per day over 200 acres, the treatment system receives an average of 0.8 inches per day over the entire area. During times of peak flowrates and grass harvesting season, certain areas have received as high as 2 inches per day for short periods of time with no decrease in treatment efficiency.

Paris Plant

Like Sumter, the Paris spray irrigation system has achieved excellent results. At Paris, the system design was based upon an application rate of 0.25 inches per day in winter and 0.50 inches per day in summer based upon an estimated wetted area coverage of approximately 75%. As it turned out, the actual wetted area was considerably less than the estimate, but the disposal capacity per wetted acre was much greater. The actual application rates amount to about 4 million gallons of wastewater per day or approximately 0.6 inches per day, with higher rates occurring during hay harvesting periods.

TABLE 2. Treatment efficiency of the overland flow system

Parameter	Mean concentration, mg/l		% removal	
	Wastewater	Section effluent	Concentration basis	Mass basis
Total suspended solids	263	16	93.5	98.2
Total organic carbon	264	23	90.8	—
Biochemical oxygen demand	616	9	98.5	99.1
Total phosphorus	7.6	4.3	42.5	61.5
Total nitrogen	17.4	2.8	83.9	91.5

The actual treatment efficiency of the Paris overland flow system is shown in Table 2. While BOD and suspended solids removal efficiencies are known to remain extremely high through many different variations of operating procedures, nutrient removal efficiencies, particularly phosphorus, however, have been found to be much more dependent upon the operational program of the system. It has been found that treatment efficiency can be improved by spreading the wastewater load over a greater fraction of the land area and by reducing the frequency of application. The greatest change is found in phosphorus removal, which can be increased to up to 88% by changing from the normal one-per-day application

to a three-per-week schedule. The figures in Table 2 are yearly averages based on a once-per-day application rate.

SUMMARY

As the value of our land and waterways becomes of ever-increasing importance, it is necessary to construct wastewater treatment systems that will not further impair the quality of the environment. While trying to attain this goal, Campbell Soup Company has adopted a policy of always attempting to adapt its waste-treatment systems to the natural surroundings. Campbell's plants at Sumter, South Carolina, and Paris, Texas, have accomplished all of the above and more. Although the treated wastewater which leaves the plant properties is of an exceptionally high quality, the waste-treatment systems have provided benefits other than just upholding the existing quality of the receiving streams. They have become good soil-conservation systems in that they have provided a nutrient-rich environment for the soils and grasses to utilize. The thick growth of grasses on the irrigation fields has also prevented a great deal of soil erosion from occurring. Finally, the irrigation fields have improved the general aesthetic characteristics of the land itself. The polishing pond at Sumter, in particular, has become a "natural" habitat for a wide variety of birds, fish, and other wildlife, an excellent example of a wastewater-treatment system that actually enhances rather than degrades the environment.

The spray irrigation technique of wastewater disposal is now being used widely throughout the food-processing industry. Most of these installations achieve a high degree of water purification, but the use of this technique is usually limited to soil areas with high infiltration capacity and thus, the purified water is usually lost to the original user. The system at Paris, Texas, is a notable departure from the usual spray irrigation concept since it employs the overland flow technique whereby water is applied to impervious soil and the purified effluent is collected at the foot of a vegetative slope. Thus, consideration can be given to the collection and reuse of water from such a system.

No attempt has been made to assess all the technology for reducing water pollutants and their effects. Our own experience indicates more attention should be focused on the land and its proper management. We concur with Professor Hinrich Bohn's very succinct letter to the Environment Editor of the *Saturday Review*, May 2, 1970.

> Soils have an enormous and as yet underexploited capacity to absorb pollutants and convert them into plant nutrients or innocuous substances. The amount of natural plant and animal wastes now decomposed by soil is far less than its potential capacity. Soil pollution has meaning only with regard to radionuclides, pesticides, and excess salts, and even they, with the exception of salts, are far less harmful in soil than in the atmosphere, rivers, and oceans.
>
> Pollution occurs when waters and the atmosphere are the final site (sink) of pollutants, or when they convey pollutants to a sink. The soil is an ideal pollutant sink, because it is far more reactive and has a greater pollutant capacity than waters or the atmosphere. . . . Organic matter would be oxidized to carbon dioxide or converted to humic matter, phosphates would be held avidly by the soil, and nitrates would be absorbed or denitrified by plants and soil microorganisms. High-quality water would be produced and would be available for reuse. At present, we waste our sewage water by dumping it into the sea and polluting it with salt.
>
> An obsession to move our wastes as fast and as far away as possible has led us to use air and water as pollutant sinks and conveyors, and therefore caused pollution. Using the soil as our pollutant sink, we can live with our wastes and even profit by them.

It appears that we have barely tapped our greatest resource for pollution control and abatement—perhaps we should get back to nature and the land.

ACKNOWLEDGMENT

A one-year study was conducted by Clemson University on the Sumter spray irrigation system. This study traced the hydrological effects of the applied wastewater and the role of the plants and soils in the system. Figures 7 and 8 are results of this study.

A one-year comprehensive cooperative study was conducted in evaluating the efficiency of the Paris treatment system. The EPA Robert S. Kerr Water Research Center in Ada, Oklahoma, evaluated primarily hydrological data and chemical efficiencies. Campbell Soup Company also sponsored biological and bacteriological research by North Texas State University and climatological and agricultural investigations by C. W. Thornthwaite Associates. Tables 1 and 2 and Figs. 9 and 10 are a summary of the full year's data.

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DISCUSSION

SHELDON: I wonder if there are any speakers on the topic of the recycling of solid wastes, sludge, wastewaters and so forth, who would like to comment on the question would recycling, taken to its extreme, ever be able to have a major impact on the other system of fertilizing in the U.S. which is essentially applying chemical fertilizer with all of the bad effects.

WALKER: I might comment. We made a calculation concerning the potential use of dewatered sewage sludge on land. If you used all that is produced in the United States it would only apply about 1% of the total nitrogen needs, about 2% of the phosphorus needs, and about 0.2% of the potassium needs. So use of this form of sludge would not have a very great total impact on fertilizer use in the United States.

SHELDON: But does that have to do with all the fertilizers?

WALKER: Those calculations had nothing to do with domestic animal wastes. I was speaking only of municipal waste.

SHELDON: But don't some animal wastes in dairies very close to cities get into the system and become part of the sludge?

WALKER: They're not supposed to.

PARIZEK: A point of clarification. That's the sludge, not the effluent?

WALKER: That's right.

PARIZEK: We have many thousands of acres of land under irrigation in some parts of the United States, where the nutrient load is in fact being obtained from the sewage effluent. I think then the figure could be increased. I'm not sure what it would be on a national average. But some major metropolitan areas are being carefully studied for land disposal involving millions of gallons of water a day. The Muskeegan, Michigan, project is in the 30 million gallons of water a day range, which is a very vast project. It's in its first year of operation this summer. Its crop projection may return roughly one million dollars this year. Its first year in full operation. This will increase as the efficiency of the system gets worked out. We do have some big examples underway.

SHELDON: One would hope that it would be possible to establish a complete cycle of using sludges and wastes by returning them to the field, and if this was done completely you would establish a long-term, steady state in the place of the present system which is not a steady state. Am I to understand that this is kind of a pipe dream or not?

VECCHIOLI: I wanted to add a little to the comment on the previous question. There are also projects in which ammonia is being removed from wastewater by cation exchange techniques and fertilizers are generated as by-products. So here we're utilizing the nitrogen even though we are first treating the wastewater through sanitary engineering techniques and then developing a fertilizer. A major problem, Dick, using Long Island as an example, is that most of the wastewater is generated in an area which is at least 50 to 75 miles away from what little farm land remains adjoining that part of the New York megalopolis. One would have to provide extensive pipelines to convey the water collected in the urban areas to nearby agricultural lands to be able to utilize the nutrient material in the wastewater.

DIGESTED SLUDGE RECYCLE TO LAND—AN ASSESSMENT OF ITS BENEFICIAL EFFECTS ON CROPS, SOILS, AND WATER RESOURCES

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Abstract. The effects of digested sewage-sludge application on the chemical composition of soil, plant and water samples from sludge amended farm and strip-mined lands are discussed. Specific hygienic aspects of digested sludge were also investigated and it was found that viruses are not likely to survive the heated anaerobic digestor environment and, although freshly digested sludge contains large populations of fecal coliform bacteria, these organisms die away rather rapidly during storage and after spreading on the soil as a surficial application of sludge. Results from these studies indicate that several crop plants show favorable growth responses when fertilized with digested sludge. With increasingly greater sludge applications, concentration levels of several chemical elements in soils are correspondingly increased above native amounts and their levels are also increased in plant tissues. The first limiting factor in determining digested sludge application rates on crop lands is its N content. As long as digested sludge application rates do not exceed those which will result in unacceptable concentration levels of NO_3-N in drainage or ground waters, sludge of the quality employed in this study can be safely used to increase the production of good-quality crops. If digested sludge is continuously applied on land at rates which supply N in amounts which greatly exceed the plants' capacity to utilize it, soluble P and some of the more soluble heavy metal constituents of sludge may eventually adversely effect the growth of crops or result in the accumulation of some chemical element in crop tissues. Studies are in progress to determine the fate of several selected chemical elements added to cropped soils as constituents of the digested sludge which has been applied annually at various rates since 1968. The results from these several studies show that P, Cu, Ni, Zn, and Cd should be given special consideration with regard to monitoring their accumulation in soils, absorption by crops, and transport in percolating water when digested sludge is used as a soil amendment. Following single heavy applications of digested sewage sludge, the agronomic properties of strip-mined acid soils were found to improve considerably, to the extent that this procedure is now being used on a large scale to revegetate these acid soils.

INTRODUCTION

The disposal of the solid residues resulting from wastewater treatment has traditionally been the most difficult problem facing municipally owned wastewater-treatment facilities. Today, sufficient technology exists to economically resolve most wastewater-treatment problems, but the true solution to the ultimate disposal of residual wastewater-treatment solids (sludge) remains a challenging and perplexing problem.

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Municipal Sludge Production

There is no precise national inventory of the quantities of municipal sludges produced in the United States although there are some estimates available. These estimates are based primarily on domestic population, and the typical amounts of sludge generated per capita. These estimates do not include the quantities of sludges resulting from the discharge of industrial wastewaters in municipal systems.

Dean (1973) has estimated that wastewaters from the national population of 200 million results in 20,000 tons/day of sludges.

Fuhrman (1973) has estimated that the actual national quantity of sludge in 1972 is approximately 3.6 million tons/year (or about 10,000 tons/day). This estimate is lower because it is based on only the sewered population and includes the effect of process variations such as digestion and incineration. By 1990, he estimates that the quantity of sludge will increase to 4.7 million tons/year (or about 13,000 tons/day). These estimates do not include industrial users of municipal plants. The authors believe that both these estimates are low. For example, the Metropolitan Sanitary District of Greater Chicago (MSDGC) produces approximately 700 dry tons of sludge solids per day for ultimate disposal from a population of 5.5 million people plus the industrial contribution. This rate of sludge production translates to about 25,500 tons/day or 9.3 million tons per year for a population of 200 million. It is clear from these estimates that by 1990 the municipal sludge production in the United States could range from approximately 5.0 to 11.5 million tons per year, assuming a United States population of 246* million by 1990.

Regardless of which estimate is accepted, it is evident that the problem of ultimate sludge disposal is not decreasing but rather increasing.

Ultimate Sludge Disposal Alternates

Basically, there are only four discrete methods of ultimate sludge disposal practically available today. These are:

1. land spreading,
2. incineration,
3. ocean disposal, and
4. land fill (containment).

Naturally, there are many combinations and variations to the above general concepts, but for the purposes here, only these four basic modes will be discussed.

Incineration

Incineration essentially involves the combustion of the organics contained in sludge. Normally, this means that approximately 30–35% (dry weight) of the sludge remains in the form of ash which must be disposed of. The primary advantage claimed for incineration is that it reduces the volume of the material for disposal. However, the process requires much energy in order to burn the high-water content sludge while the fertilizer value of the sludge is simultaneously destroyed. The process also incurs significant costs for sludge

* U.S. Census Bureau estimate.

dewatering, and the ash does require a land-disposal site. The incineration process also releases significant quantities of pollutants to the air including volatilized metals. Air-pollution-control technology for removal of metals is expensive and is not likely to meet the emerging governmental regulations. For the Metropolitan Sanitary District of Greater Chicago, incineration is estimated to cost from $90 to $100 per dry ton of sewage-sludge solids excluding any costs for removal of metals from stack gases.

The current fuel shortage has cast an additional gloomy shadow on sludge disposal by incineration. The steadily increasing cost and decreasing availability of gas and oil will affect the desirability if not the feasibility and practicality of this process in the foreseeable future.

Table 1 presents some data on auxiliary fuel consumption in seven cities Olexsey *et al.* (1974). The weighted average consumption of number 2 fuel oil necessary to burn 1 ton of dry solids is 51.6 gallons. If this figure is rounded to 50 gallons per ton nationwide and one assumes that the practice of sludge incineration were adopted nationally, then the U.S. would require at least 900 million gallons of crude oil per year. In 1972 the nation was consuming only about 135,000 gallons per day (Olexsey and Farrell, 1974). Clearly, unless alternative methods for sludge disposal are available to municipalities, sludge incineration will be at variance with the long-term fuel conservation goals of the nation, regardless of the accuracy of the above estimate.

TABLE 1. Auxiliary fuel consumption for sludge incineration in cities during 1972

City	Sludge production (dry tons/day)	Fuel/dry tons of solids*
Jersey City, N.J.	15	28
Providence, R.I.	30	28
Tonawanda, N.Y.	6	17
Rochester, N.Y.	17	42
Hartford, Conn.	25	160
St. Louis, Mo.	55	22
St. Paul, Minn.	275	45

* Gallons of no. 2 oil.

In addition to the energy required to incinerate sludge, one must also consider the fact that incineration destroys the nitrogen and other agronomic nutrients contained in the sludge. This nitrogen must be replaced and, of course, it takes energy to make the required inorganic fertilizer for replacement. For example, the replacement of 1 ton of nitrogen fertilizer requires 917 gallons of crude oil. Clearly if we can recycle the nitrogen content of sludge, we can reduce the amount of energy required for fertilizer manufacture and the corresponding cost of food production.

Ocean Disposal

Ocean disposal offers, to coastal cities, a readily available ultimate sink for sludge. This had been practiced by many U.S. cities including Los Angeles and New York. However, this means of disposal is not available to most inland U.S. cities and has many disadvant-

ages. Any nutrient value contained in the sludge is wasted while the organics present tend to deplete the dissolved oxygen of the disposal site. Such disposal could significantly affect coastal fishing areas as well as reduce ocean bathing areas. This method of disposal has come under increased governmental scrutiny and may soon be severely restricted. Costs are very low for this process and include only transportation costs although some cities are beginning to digest their sludge prior to ocean disposal.

Land-fill Operations

Land-fill operations are practiced by many cities and included under this general term is sludge lagooning. Land-fill operations waste the organic content of sludge while considerable expense is involved in sludge dewatering either for lagoon decanting operations or prior to land-fill operations. Disposal sites often are useless for other purposes following land fill and some are never returned to the tax rolls. Few sites can be used for 20 to 30 years after being land filled with municipal sludges. Oftentimes, such sites produce methane gas which could cause potentially dangerous situation for other land uses.

Land Spreading

Land spreading of sludge has become a method which is being increasingly considered by many municipalities in the U.S. It offers the advantage of recycling nutrients back to the land at very low cost and of reclaiming lands bespoiled by strip mining (Hinesly *et al.*, 1971; Dalton and Murphy, 1972; Kudrna and Kelly, 1973; Peterson and Gschwind, 1973; Hinesly *et al.*, 1972; Conforth, 1972). Sludge is first stabilized by anaerobic digestion or other suitable means before application on land. Such stabilization eliminates obnoxious odors and fly problems. Yield of grain and forage crops are increased by the nutrients and water supplied by irrigating with digested sludge. Digested sludge organic matter accumulates in and imparts favorable characteristics to soils because of its normally high humus content. The process of land spreading of sludge affords the opportunity for urban areas to recycle the fertilizer value of sludge to the farming areas from which much of the organic materials and nutrients originate. With the current shortage of fuels, and the high requirements for inorganic fertilizer production, this offers a ready opportunity to reduce the energy requirements of the agricultural sector. Also, since many municipalities can offer their sludge at practically no cost to the farmer, a significant cost savings is effected.

The District estimates that the concept of land reclamation costs approximately $36 per dry ton and that it is the most economical and environmentally acceptable alternative available consistent with the concept of returning the available nutrients back to the land.

Current U.S. Practices in Sludge Utilization or Disposal

The Federal EPA Municipal Inventory shows the following current practices for sludge use or disposal throughout the U.S.:

Incineration	35%
Ocean disposal	15%
Land	50%

The "land" category includes both land-fill and land spreading procedures but presents no further quantitative breakdown.

The U.S. EPA Construction Grants Program for 1973 shows the following distribution of sludge use or disposal (EPA, 1973):

Incineration	13%
Ocean disposal	3%
Land	84%

Again, there is no quantitative breakout on the "land" category.

SLUDGE RECYCLE TO LAND

The solid materials which have been removed from municipal wastewater are considered by the District as a resource which has *beneficial uses* and which must be recycled *rather than a waste product to be discarded.* This concept is *not* new since it is presently being used on a relatively small scale nationally and on a larger scale internationally. What is new is the application of this natural system to an urbanized region of approximately 6 million people.

Utilizing solids is the only known method of returning organic materials to their natural cycle. Digested sewage sludge, the by-product of treated municipal wastewater can:

1. enhance production of crops on presently productive soil,
2. be used to reclaim substandard arid land, and
3. eliminate air and water pollution problems caused by other methods of ultimate sludge disposal.

Operational Criteria

The above features of a digested sludge-recycle program incorporate all the criteria established by the governing board of the MSDGC to be met by any long-term ultimate sludge disposal scheme, namely:

1. It should not contribute to any environmental pollution (air or water).
2. It should conserve the organic matter for beneficial uses.
3. It should be economical.
4. It should be permanent, i.e. it should complete the natural cycle.

Agronomic Values of Digested Sludge

Heated anaerobically digested sludge is outstanding in its ability to increase the humus content of soils. For example, in 1941 a study was initiated at the Rothamsted Experiment Station in England to compare the effects of four types of organic manures with inorganic N fertilizers on market-garden crops (Mann and Patterson, 1962). The organic manures were farmyard manure, digested sewage sludge, a compost of straw and sewage sludge. Each of the organic manures was applied at the rate of 33.8–67.5 t/ha per year. After 9 years, N in the top 22.9 cm of soil was 0.088% where inorganic N, the familiar fertilizer source, had been applied as compared to a value of 0.089 for control plots. At application rates of 33.8 to 67.5 t/ha per year of digested sludge, the N [illegible] in th[illegible] [illegible]rface was

ment plants have been used in the research conducted (since 1967) by members of the Agronomy Department, University of Illinois.

TABLE 2. Composition of anaerobically digested sewage sludges from MSD of Chicago, Calumet and Stickney treatment plants
Samples obtained during 1971
(Calumet late in year)

	Mean (wet weight)	
Element	Calumet	Stickney
Cd ppm	3.0	14.0
Mn ppm	8.0	18.0
Ni ppm	3.0	15.0
Zn ppm	83.0	223.0
Cu ppm	16.0	67.0
Cr ppm	26.0	194.0
Fe ppm	726.0	2100.0
Pb ppm	16.0	75.0
Hg ppm	0.063	0.275
Na ppm	98.0	131.0
P ppm	757.0	1141.0
Ca ppm	963.0	1289.0
Mg ppm	180.0	484.0
K ppm	195.0	390.0
N %	0.09	0.156
% Solid	2.05	4.36
% Volatile	58.0	48.0

Anaerobically digested sludge, as it comes from digesters, contains 3–5% solids as finely divided and dispersed particles. It looks like crude oil and has an odor which many people describe as earthy or tarry. It can be easily transferred by pipes using ordinary pumping techniques and equipment.

Microbiological Properties of Digested Sludge

Although no incidence of disease is known to have been traced to the use of digested sludge as a fertilizer or soil amendment, it is still one of the greatest sources of concern for many. From a rather extensive literature survey, it appears that most of the intestinal pathogenic bacteria are either destroyed or their populations are reduced to very low levels by heated anaerobic digestion of sewage solids. Results from several studies indicate that the pathogenic organisms of tubercle bacillus, *Taenia sabinata*, *Ascaris lumbricoides*, and hookworm are not destroyed as rapidly in a heated anaerobic digester as are the commonly used pathogenic indicator organisms, *Escherichia coil* or fecal coliforms.

One of the most crucial questions which could not be answered from a search of the literature was that of the fate of viruses during the anaerobic digestion of sewage solids. Even if viruses were not recovered from digested sludge, one could not be sure that they were not present in an adsorbed phase on the solids. To answer the question regarding the survival of viruses in the heated anaerobic digester environment, we initiated some labora-

tory studies using a swine enterovirus (ECPO-1) which has bio-physical properties similar to human enteric viruses. After gas production had stabilized in six laboratory scale digesters fed with a mixture of primary and waste-activated sludge, they were inoculated with 10^5/ml of plaque forming units of the swine virus. After inoculation, 20 ml of fluid were periodically withdrawn from the digesters and mixed with milk and fed to germ-free piglets. The feces from the piglets were then collected and assayed for the viable virus. The viruses were not found in the feces of piglets fed sludge material which had been inoculated and digested for a period of time of 5 days or longer (Meyer *et al.*, 1971). It thus appears that a 14- or 15-day heated anaerobic digestion period would provide a considerable margin of safety with regard to the destruction of viruses.

As Berg (1966) suggested, perhaps the simplest method for reducing viruses and other pathogen organisms in sewage is by long storage of the material. From laboratory studies, Berg (1966) determined the time in days required for a 99.9% reduction in the number of viruses and bacteria by storage at different temperatures. The die-away data presented in his Table 5 are exhibited here as Table 3. On the basis of these and other data, it appears that an additional margin of safety against pathogenic contamination of the environment could be achieved by holding digested sludge in reservoirs for a minimum period of 2 months before it is applied on land.

TABLE 3. Effects of storage: laboratory study demonstrating days required for 99.9% reduction of viruses and bacteria in sewage (Berg, 1966)

	No. of days Temperature, °C		
Organism	4°	20°	28°
Poliovirus 1	110	23	17
Echovirus 7	130	41	28
Echovirus 12	60	32	20
Coxsackievirus A9	12	—	6
Aerobacter aerogenes	56	21	10
Escherichia coli	48	20	12
Streptococcus faecalis	48	26	14

Very little work has been reported on the inactivation of viruses during the anaerobic digestion of sewage sludges. However, at the MSDGC, the inactivation rates of the coliphage MS-2 and of four human enteric viruses (poliovirus type 1, coxsackievirus type A-9, coxsackievirus type B-4 and echovirus type 11) were determined and compared, using laboratory scale anaerobic digesters seeded with these viruses Bertucci *et al.* (1973, 1974). The sludge was obtained from the West-Southwest Treatment Plant and the operating parameters of the laboratory digesters were the same as those of the full-scale plant.

The results of this study show that:

1. Poliovirus type 1 titers were inactivated an average of 93.8% in 24 hours and 98.5% in 48 hours.
2. Coxsackievirus Type A-9 was inactivated an average of 97.5% in 24 hours and 99.7% in 48 hours.

3. Coxsackievirus Type B-4 was inactivated an average of 89.5% in 24 hours and 98.6% in 48 hours.
4. Echovirus Type 11 was inactivated an average of 58.0% in 24 hours and 92.5% in 48 hours.
5. For the MS-2 coliphage there was 87.7–96.3% inactivation after 24 hours, and 99–99.6% inactivation after 48 hours.

As indicated in this study, anaerobic digestion results in rapid and significant virus inactivation. Projecting from the survival or inactivation curves, the D values (90% reduction times) are of the order of 1 day (Bertucci *et al.*, 1973, 1974). With the District's average digester retention time of 14 days, there seems little likelihood that significant quantities of viruses can survive the anaerobic digestion process and subsequent handling of the sludge which includes shipment (2–3 days) and lagooning for several months, prior to its application on land.

After sludge is applied on the soil surface, die-away of many pathogenic organisms will occur rapidly as seen from the data in Table 4. The rapidity with which fecal coliform die-away occurs after digested sludge is applied on soil surfaces can be discerned in Table 4.

TABLE 4. Disappearance of fecal coliforms in a sludge cake covering a soil surface (Unpublished data, Agron. Dept., University of Illinois)

Days after sludge application	No. of fecal coliforms per gram sludge cake (dry weight)
1	3,680,000
2	655,000
3	590,000
5	45,000
7	30,000
12	700

Furthermore, it has generally been concluded that wastewaters percolating through unsaturated soil materials are purged of pathogenic organisms within the 1.5-m depth Butler *et al.* (1954). If this is true for wastewater applications, one would expect it to be applicable in the case of sludge utilization. Since sludge solids are rapidly filtered and clog the surface of soils, the rate of water infiltration during sludge applications is exceedingly low in comparison to that from wastewater applications. Therefore, frequent applications of sludge can be made only when the evapotranspiration potential is relatively high. That is to say, sludge is most likely to be applied on agricultural lands during the late spring, summer, and early fall seasons when evapotranspirational potentials generally exceed actual soil moisture losses. For the most part, sludge will be applied when ambient temperatures favor a rapid die-away of bacterial and viral pathogenic organisms.

Like many of the potential chemical water pollutants, lateral movement of pathogenic organisms which might survive the digestion and storage period can occur only if excessive soil-erosion processes are permitted to operate on the sludge-utilization site. Thus, pathogenic pollution of surface waters can be avoided by the same structural and management practices recommended for the conservation of soil and water.

Land Requirements

If all municipal wastewaters generated in the continental United States were given secondary treatment and the resulting solids stabilized for utilization as a fertilizer and soil amendment, about 9.0 to 10.5 million metric tons of solids would be available each year. The utilization of the solids in amounts just sufficient to meet the needs of nonleguminous crops for supplemental N would require an annual application of about 22.5–33.7 t/ha. Thus, not more than 0.4 million hectares of land would be required at any time to utilize the total continental United States production of sludge solids. Only enough sludge solids would be available to treat slightly more than 0.2% of the 188 million hectares of cropland or slightly less than 0.06% of the total 771 million hectares contained in the continental United States. However, because of its potential as a source of sorely needed stable organic matter, municipal sludge exhibits its greatest value as a resource when used as an amendment for the reclamation of surface-mined lands. Since over 0.2 million hectares of land strip-mined for coal prior to 1964 already exist in various states of devastation, while another 0.2 million hectares have been or will be stripped during the 20-year period from 1964 to 1984, there is no scarcity of land which needs the nutrients and organic matter supplied in sludge. About 30% of the country's population is within economical sludge pumping distances to land that has been strip-mined for coal in Illinois, Indiana, Kentucky, Ohio, West Virginia, and Pennsylvania.

Those who express concern about the contamination of soils with constituents of municipal sludges probably are not aware of the relatively small amount of land needed. Confusion often exists between land requirements for sewage-effluent disposal or renovation and that needed for solids utilization.

Criteria for Selection of Sludge-utilization Sites

In utilizing digested sludge as a soil amendment and fertilizer, the following criteria for site selection are recommended. (a) The site should be located where utilization of the sludge offers maximum benefits to the local agricultural economy, consistent with reasonable costs to the particular sanitary district. The local populace must be able to weigh the benefits to be realized from the sludge-utilization program against the assumed or real stigma attached to an area that becomes the receptor of waste from a large municipality. People living in areas devastated by surface mining activities readily recognize the benefits to be realized by utilization of digested sludge to reclaim land. (b) To ensure that sludge applications are made under uniformly controlled conditions, the land must be susceptible to purchase or long-term lease by the sanitary district. (c) To minimize sludge distribution cost, all lands in the site should be contiguous, at least to the extent that the disturbance to existing residents is minimal. Surface-mined lands offer the best possibilities for obtaining large, contiguous acreage. There is little or no disturbance of existing residents, because this occurred during the stripping process. It is envisioned that much of the land will be repopulated with farm operators as the land is reclaimed to a high state of productivity. (d) Soil depths should not be less than 1.83 m to permeable bedrock. Water tables should be capable of being maintained to average depths of at least 1.83 m from the soil surface. Such minimum soil depths, with good management practices, will provide protection from ground water pollution. (e) Land slopes should not be so steep as to prohibit the establishment of water management and erosion-control structures at a reasonable cost. Slopes up

to 18% may be acceptable with "push-up" terraces where permanently vegetated or sodded back slopes can be established. Unconsolidated geological materials must be sufficiently deep to bedrock in the borrow area so that after terrace construction a minimum 1.83 m depth to bedrock is maintained.

Loading Rates

When applied to cropland at the rate of 5 cm/ha, it will supply all of the major essential nutrients, including: 224–392 kg/ha of NH_4–N; about the same amount of organic N, some of which will be slowly released in a form available to crops; 280–504 kg of P, of which about 80% is in organic matter; and 45–90 kg of K. Sulfur will also be supplied in amounts adequate for crops. The amounts of Ca and Mg supplied will exceed the average annual losses of these elements by leaching in humid regions.

High application rates of digested sludge on cropland can cause obvious NO_3 problems. To determine maximum sludge-loading rates on soils, total and soluble nitrogen contents must be known. The soluble N in anaerobically digested sludge is in the NH_4–N form, but under proper soil aerobic and temperature conditions it is rapidly converted to mobile NO_3–N.

Thus, the loading rate of sludge on cropland is limited by the amount of soluble N plus an annual mineralization of the organic N supplied by sludge applications. If loading rates are based on the amount of N furnished to meet crop needs and losses by volatilization, soluble P applications will also be at low enough levels that P will not present a eutrophication threat to water supplies. When sludge-loading rates are based on safe N application rates, the capacity of most soils other than sands to inactivate P by adsorption and conversion to sparingly soluble precipitates or compounds is great enough to maintain P levels in drainage water to less than 1 ppm.

When the main objective is land reclamation, sludge-loading rates may be considerably greater because disturbed lands generally have small or nonexistent organic N reservoirs. The amelioratory effect of organic matter on the physical properties of soil materials may make it desirable to increase sludge-loading rates on marginal or severely disturbed lands above those recommended for productive agricultural lands. However, as the highly stabilized sludge organic matter accumulates in soils with succeeding applications, the slow mineralization of organic N must be taken into account to prevent losses of NO_3–N to water supplies, within or adjacent to the treated areas.

Many toxic and nontoxic organic waste materials occurring as constituents of sludge arise as discharges from industrial processes, such as the chemical production of textiles, plastics, pharmaceuticals, detergents, and pesticides. After a period of microbial acclimation, some organic toxic substances, such as phenols and formaldehyde, can be almost completely removed from wastewater by biological treatment, even though at sufficiently high concentrations they are bactericidal Jackson *et al.* (1970). Others, which are nonbiodegradable under aerobic conditions, may be removed from effluent with or by absorption on sludge sediments and later biologically degraded during anaerobic digestion of the solids. Of all the organic materials, polychlorinated biphenyls (PCB's) have been of greatest concern to those involved with municipal waste utilization. Many sludges contain 1–4 ppm or more, and like other chlorinated hydrocarbons, PCB's are only very slowly degraded by microorganisms. Where we have applied 105 metric tons of digested sludge a small increased

concentration of PCB's was found in the soil, but they were not taken up in detect concentrations in soybean and corn plant tissues. Since bacteria are the first group of microorganisms to be decreased by abnormally high concentrations of chlorinated hy carbons, we have made total counts from soil samples collected from plots which l been treated with up to 124 metric tons of sludge over a period of 4 years. Total bact populations were found to be higher in soils treated with sludge. The positive correla between total bacteria and amounts of applied sludge was highly significant. It app that sludge applications have modified the soil environment in a manner that favors maintenance of a highly active population of bacteria resulting in a greater rate of pesti degradation than might be expected in soils not treated with sludge.

SOIL AND CROP RESPONSES TO SLUDGE APPLICATION ON LAND

Cities as large as Paris, Berlin, and Melbourne have operated "sewage farms" to disp of sewage and sludge for several decades. Rohde (1962), however, has claimed that the s at the sewage farms operated by Paris and Berlin have become exhausted due to h accumulated levels of Zn and Cu. Leeper (1974) reviewed Rohde's work and that of Tro *et al.* (1950) who reported on manganese deficiency in vegetables at the Paris farm, reinterpreted their data. According to Leeper, the problem at the Paris farm was not and Cu phytotoxicity but rather Zn deficiency which Troene *et al.* reported had occur around Paris before 1925.

Melbourne has operated a sewage farm since 1897 at Werribee, Australia. Johnson *e* (1974) analyzed tissue from selected sites on the farm and concluded that in regard food chain effects, forage contained neither excessive nor deficient amounts of trace ments. These results are very significant for helping determine the long-term effects sludge application or recycle to land.

The Metropolitan Sanitary District of Greater Chicago adopted the concept of slu recycle to land in 1966 and proceeded to develop experimental corn plots from a 2 hectare (7-acre) field at its Hanover Park Wastewater Reclamation Plant in 1968 to de mine the environmental effects of sludge application to land. The original experimer design was a randomized block with five replications and three sludge loading rates o 6, and 12 mm of sludge/week. Sludge was applied at weekly intervals in furrows betw the growing corn rows. Soil and corn leaf samples were taken annually and analyzed various chemical or physical-chemical characteristics. In 1973 corn grain was also analyz Groundwater and surface drainage water were sampled weekly and analyzed for chemi and fecal coliform content. This section presents the results through 1973 which inclu 6 years of sludge application.

Hanover Park Experimental Corn Plots

In 1968 a 2.8-hectare field south of the Hanover Park Wastewater Treatment Plant v selected for development of experimental corn plots for sludge fertilization. In order grade plots for furrow irrigation, the topsoil was stripped, the subsoil graded to desi slope, and the topsoil was replaced. The soil has been characterized as a disturbed Drumn silty clay loam with poor natural drainage. The original experimental design was a ra domized block with five replications having grades of 0.5, 1.5, and 2.5%.

Four monitoring wells approximately 6 m in depth were placed at the corners of the field plots for sampling groundwater leachate. A single-tile drain bisects the field of plots draining from south to north. This tile was overlain with gravel. These plots are shown in Fig. 1.

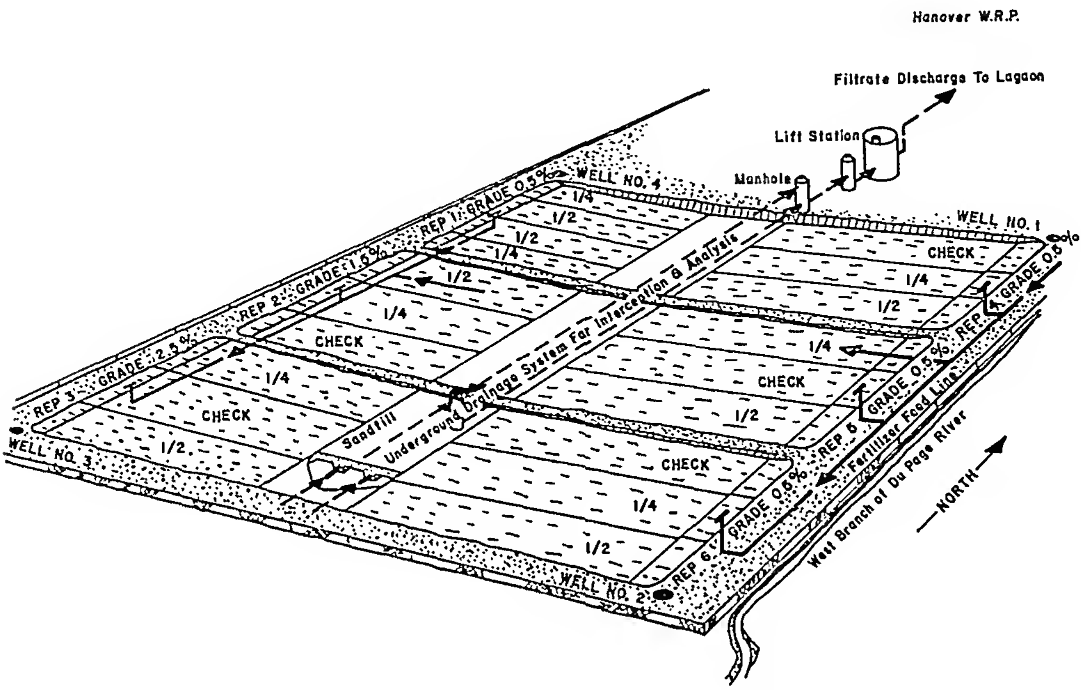

Fig. 1. Liquid digested sewage sludge utilization on land Hanover W.R.P. research site

Methods

The monitoring wells and field tile drain were sampled weekly. These were analyzed according to *Standard Methods for the Examination of Water and Wastewater*, 13th edition (1971).

Soil samples were taken in spring and were composites of twenty cores, 0–15 cm deep. The samples were air dried and then analyzed for pH (Peech, 1965) and electrical conductivity (Bower and Wilcox, 1965); 1/3 bar moisture content (Richards, 1965), organic carbon content (Allison, 1965), cation-exchange capacity and exchangeable K, Na, Ca, Mg (Chapman, 1975), and 0.1 N HCl extractable Zn, Cd, Cu, Cr, Fe, Ni, Pb, Mn, and Al (1:10 soil to 0.1 N HCl solution).

The corn leaf opposite the ear was collected at the tasseling stage each year. These samples were immediately washed with distilled water, dried in a forced air drying oven at 60°C, ground in a Wiley mill, and analyzed for trace metal content. Trace metals were determined by dry ashing plant tissue at 450°C, taking up the ash in the 0.1 N HCl, and analysis by atomic absorption.

Corn grain analysis for trace metal content began with the 1973 corn crop. Grain subsamples were taken during corn yield determinations. Grain was dry ashed at 450°C, taken up in 0.1 N HCl, and analyzed by atomic absorption spectroscopy.

Each spring the plots were plowed and harrowed. Ridges and furrows were formed

parallel to field slope. Sludge was applied from gated irrigation pipes at the upper end of the plots and allowed to flow down the furrows.

The plots have been fertilized with sludge every year beginning in 1968. Sludge application has not been replicated according to the original design. Most of the sludge applied came directly from heated anaerobic digesters at the Hanover Sewage Plant. On a few instances, lagooned digested sludge was also applied. The average analysis for digester sludge applied each year is presented in Table 5.

TABLE 5. Average annual chemical content of the liquid digested sludge applied to the Hanover Park experimental corn plots from 1969 through 1973. These plots have received liquid sludge from 1968 through 1973

	Year				
	1969	1970	1971	1972	1973
ph	7.2–8.1	6.8–8.4	7.1–7.9	6.8–7.7	7.1–7.6
Total solids (TS) %	3.92	4.41	3.13	5.74	3.40
Vol. solids % of TS	41.1	40.8	49.9	32.5	46.6
			% dry basis		
Total P	3.45	1.60	2.72	1.06	1.42
Total N	5.6	5.39	4.29	2.63	4.61
NH_3-N	3.7	4.04	2.38	1.52	2.44
Cl	—	0.12	—	0.28	0.77
Alk as $CaCO_3$	8.20	1.80	7.83	4.31	6.37
Fe	1.8	3.3	1.55	1.89	1.72
Zn	0.07	0.069	0.068	0.080	0.072
Cu	0.045	0.054	0.087	0.056	0.070
Ni	0.005	0.049	0.042	0.017	0.008
Mn	0.07	—	—	0.02	0.051
K	0.68	—	—	0.23	0.26
Na	0.3	—	—	0.29	0.50
Mg	1.64	—	—	1.19	1.22
Ca	5.05	—	—	2.56	2.89
Pb	0.08	0.051	0.017	0.011	0.017
Cr	0.005	0.015	0.037	0.021	0.022
Cd	0.005	0.012	0.010	0.002	0.004
Al	—	3.21	1.73	1.57	1.05

Effect of Sludge Application on Agricultural Soil

Analysis of the soil from the control plots showed depletion of some major nutrients due to leaching and crop removal (Table 6). This was especially evident for available phosphorus. The electrical conductivity (EC) also indicated the overall decrease of soluble salts over the 4-year period measurements were taken.

There has been a steady decrease in the organic carbon content of the untreated soil since it was planted to corn. In 1968, 1972, and 1973 all plots received potash application as it was observed that exchangeable potassium was decreasing. This addition is reflected in the 1973 soil analysis which showed a return to near the 1970 potassium content.

Soil pH has dropped 0.60 pH units on all plots from 1970 to 1973. There was no

TABLE 6. Chemical and physical properties of a distributed Drummer silty clay loam collected from 1970 through 1973 from the Hanover Park experimental corn plots. These plots have received liquid sludge from 1968 through 1973

Parameter	1970			1971		
	Weekly sludge application (mm)					
	0	6	12	0	6	12
pH	7.9	7.7	7.7	7.7	7.4	7.5
EC, μmhos/cm	N.A.*	N.A.	N.A.	0.50	0.61	0.87
CEC, meq/100 g	33.4	34.0	32.2	27.2	32.2	32.7
1/3 bar H_2O, %	38.0	38.0	36.8	32.8	34.5	33.3
C-organic, %	3.08	3.21	3.15	2.97	3.52	3.27
P-available, μg/g	N.A.	N.A.	N.A.	21.3	51.8	63.4
Exchangeable bases						
K μg/g	138	158	153	139	139	141
Na ,,	95	131	117	61	78	87
Ca ,,	5440	5660	5530	5360	5590	5310
Mg ,,	1520	1600	1600	1450	1480	1420
0.1 N HCl extractable						
Fe μg/g	813	827	835	775	584	669
Mn ,,	253	281	290	224	224	254
Zn ,,	30.5	39.0	37.5	32.8	43.6	41.6
Cd ,,	0.7	0.7	0.5	N.A.	N.A.	N.A.
Cu ,,	18.3	66.6	33.8	8.19	3.31	14.4
Cr ,,	1.7	2.30	5.2	3.28	3.31	3.86
Ni ,,	11.3	10.9	10.9	9.2	10.3	11.0
Pb ,,	16.2	11.8	13.3	8.12	9.29	9.42
Al ,,	2010	2750	2680	3180	2780	3240

* N.A.=no analysis.

Parameter	1972			1973		
	Weekly sludge application (mm)					
	0	6	12	0	6	12
pH	7.7	7.6	7.6	7.3	7.1	7.1
EC, μmhos/cm	0.44	0.53	0.70	0.41	0.51	0.61
CEC, meq/100 g	32.2	35.0	36.0	33.9	33.7	33.3
1/3 bar H_2O, %	31.4	32.5	32.5	32.2	33.1	32.2
C-organic, %	2.70	3.28	3.00	2.61	3.37	3.33
P-available, μg/g	15.8	22.4	39.6	9.8	51.5	79.8
Exchangeable bases						
K μg/g	104	106	90	126	149	126
Na ,,	125	157	167	25	30	44
Ca ,,	4160	4100	3620	5140	6300	5650
Mg ,,	1110	1120	1030	1660	1700	1690
0.1 N HCl extractable						
Fe μg/g	116	191	207	301	339	346
Mn ,,	132	143	139	198	200	195
Zn ,,	43.8	52.8	66.0	24.4	23.4	27.6
Cd ,,	0.18	0.34	0.33	0.68	0.58	0.61
Cu ,,	5.38	11.9	14.9	6.72	13.3	15.8
Cr ,,	0.13	0.58	0.99	0.93	1.26	1.47
Ni ,,	5.88	7.14	6.80	8.60	9.11	8.93
Pb ,,	6.00	6.80	7.20	8.25	9.21	9.68
Al ,,	926	1010	968	1700	1770	1820

influence on soil pH from sludge application but liming may be necessary on all plots in a few years.

The application of liquid digested sludge has resulted in stabilization or increases in most of the soil parameters analyzed. The most significant increase was in available phosphorus. For the plots receiving 6 mm of sludge per week, after 6 years, the available phosphorus content was 5 times that of the control plots. For the 12 mm of sludge per week application, this value was 8 times that found in the control. There were also increases in

TABLE 7. Range of chemical content of corn leaves collected from 1969 through 1973 from the Hanover Park experimental corn plots which have received liquid sludge from 1968 through 1973

	Year			
	1969		1970	
Element	with sludge	without sludge	with sludge	without sludge
	μg/g dry weight basis			
K	9,980 –23,400	21,500 –28,500	17,280 –23,450	19,370 –22,920
Ca	5,300 – 9,400	3,300 – 4,300	4,590 – 6,730	3,700 – 4,550
Mg	3,300 – 8,100	1,900 – 3,500	2,470 – 5,210	2,680 – 3,310
Fe	156 – 222	103 – 144	62 – 177	117 – 156
Mn	34 – 61	25 – 32	45 – 65	39 – 52
Zn	19 – 49	8 – 12	29 – 90	15 – 90
Cu	5 – 24	7 – 12	5.9– 12.1	5 – 14
Na	N.A*	N.A.	51 – 122	50 – 87
Cr	6.1– 11.5	6.1– 12.5	2.7– 7.9	0.4– 7.1
Ni	2.0– 4.6	1.0– 4.5	0.5– 2.2	0.4– 8.0
Cd	2.3– 3.2	2.5– 3.1	0.5– 3.3	0.4– 1.0
Pb	2.3– 8.8	6.1– 9.0	4.9– 10.5	6.0– 7.8
Accumulative sludge, metric tons dry solids per hectare	30 – 65	0	30 – 65	0

* N.A.=no analysis.

	1971		1972	
Element	with sludge	without sludge	with sludge	without sludge
	μg/g dry weight basis			
K	9,980 –17,600	13,100 –17,340	10,130 –17,050	14,820 –19,220
Ca	4,500 – 7,730	4,120 – 7,510	5,470 –10,880	4,300 – 5,820
Mg	2,820 – 6,590	2,700 – 3,830	3,590 – 7,160	3,500 – 5,200
Fe	93 – 130	48 – 134	174 – 274	171 – 240
Mn	35 – 70	31 – 48	24 – 39	22 – 30
Zn	46 – 100	38 – 50	30 – 56	17 – 23
Cu	11.3– 16.2	8.6– 10.0	7.7– 13.5	6.4– 8.9
Na	13 – 27	15 – 24	70 – 224	99 – 124
Cr	0.9– 2.9	0.9– 1.4	1.1– 2.8	1.1– 2.3
Ni	0.9– 5.0	4.5– 5.0	1.2– 12.6	1.7– 12.1
Cd	0.9– 2.2	<1.0	1.2– 3.4	1.1– 1.2
Pb	4.1– 5.4	3.4– 4.8	9.8– 28.7	9.7– 15.8
Accumulative sludge, metric tons dry solids per hectare	53 – 119	0	63 – 139	0

TABLE 7 *cont.*

Element	Year	
	with sludge	without sludge
	μg/g dry weight basis	
K	12,450 –18,470	15,140 16,210
Ca	4,550 – 6,090	2,120 – 3,170
Mg	1,840 – 4,180	1,060 – 2,450
Fe	64 – 100	22 – 55
Mn	24 – 39	9 – 30
Zn	24 – 37	5 – 15
Cu	5.1– 11.8	1.7– 5.9
Na	39 – 58	41 – 157
Cr	0.7– 2.9	1.4– 3.6
Ni	<2.4	2.4
Cd	<0.2	0.2
Pb	0.4– 2.5	0.4– 0.6
Accumulative sludge, metric tons dry solids per hectare	101 – 191	0

Cu, Na, and EC compared to the control. Hinesly *et al.* (1971) found similar increases in soil after 3 years of sludge application. Sludge application stabilized the organic carbon content of the soil, though it is not possible to determine if this is due to the increased plant residue on the fertilized plots or organic matter from sludge. There was no effect upon the cation exchange capacity (CEC).

Response of Corn to Sludge Fertilization

Metal uptake by corn was determined by analyzing corn leaf and corn grain samples. Corn leaf samples were taken each year from 1969 through 1973 while corn grain samples were first taken in 1973. Analysis of corn leaf is presented in Table 7 and of corn grain in Table 8.

TABLE 8. Range of chemical content of corn grain collected in 1973 from the Hanover Park experimental corn plots which have received liquid sludge from 1968 through 1973

Element	with sludge	without sludge
	μg/g dry weight basis	
K	3080 –4140	2520 –3260
Ca	43 – 74	55 – 68
Mg	990 –1590	1290 –1390
Fe	26 – 42	36 – 47
Mn	4.9– 7.5	4.6– 6.0
Zn	20 – 33	23 – 27
Cu	1.4– 2.2	1.4– 2.2
Na	18 – 70	20 – 42
Cr	0.5– 1.0	0.5– 1.0
Ni	<0.5	<0.5
Cd	<0.5	<0.5
Pb	0.6– 1.2	0.7– 1.2
Accumulative sludge, metric tons dry solids per hectare	107 – 203	0

Ranges of metal content are presented since there were wide variations in metal content and no significant correlations among samples from sludge-fertilized plots. Significance of metal uptake by corn leaf was also determined by analysis of variance using the mean values of metal content for each treatment for each year. There was no significant difference between the two sludge treatments for any metal, but there was a significant difference (0.01 level) between corn leaves from the sludge-applied and unfertilized plots for Zn, Mn, and Cu. The concentrations of these three metals were within the common average composition range for foliage of selected agronomic crops as reported by Melsted (1973): Zn, 15–150 ppm; Mn, 15–150 ppm; and Cu, 3–40 ppm. Analysis of variance of metal content of corn grain showed there was no significant difference between sludge-applied and unfertilized plots in 1973, the only year grain samples were analyzed, except for Ca in which there was a significant increase (at the 0.01 level) for the 6-mm/week sludge treatment.

Corn yields are presented in Table 9 from 1968 to 1973. Sludge application consistently produced yield increases.

TABLE 9. Corn yields from 1968 through 1973 for the Hanover Park experimental corn plots which have received liquid sludge from 1968 through 1973

Weekly application rate	Total sludge applied 1968–73	Year					
		68	69	70	71	72	73
mm	Metric tons/ha of solids	Corn yields metric tons/ha at 15.5% moisture					
Check	0	2.07	2.57	1.51	3.45	0.69	1.82
6	116	3.95	8.72	2.89	5.33	4.33	4.89
12	182	4.01	8.91	2.95	6.08	4.95	6.21

Effect of Sludge Application on Groundwater

Monitoring wells in each corner of the field plots and surface drainage were sampled weekly since 1969 and analyzed for various chemical parameters and fecal coliform content. These results were averaged annually for groundwater drainage (the average of the four wells) which is presented in Table 10 and the tile drainage presented in Table 11. There has been an overall decrease in groundwater for K, Na, Ca, Mg, Zn, Cu, Mn, Fe, $SO_4^=$, Kjeldahl-N, NH_3—N, and alkalinity. Increases were observed for Cl^- NO_2+NO_3—N, and pH. Only Fe consistently exceeded the U.S.P.H.S. drinking water standard of 0.3 mg Fe/l. The Fe content has no significance with regard to public health. The pH of the groundwater increased 0.5 pH units from 1968 to 1969 and remained relatively constant from 1969 to 1973. The alkalinity, Ca, and Mg concentrations of the groundwater decreased from 1968 to 1973 (Table 10).

Considering the quantity of nitrogen applied (Table 5 and Table 7), it is noteworthy that NO_2+NO_3–N concentration in the groundwater leachate has not increased above 0.4 mg/l and it even appears that a plateau concentration exists for 1970–3. Braids *et al.* (1970) observed that nitrate nitrogen was the only toxic chemical which increased in leachate from sludge-amended soil in lysimeters when nearly 5 metric tons of nitrogen/hectare were

TABLE 10. Average annual chemical and fecal coliform content of leachate collected weekly from four monitoring wells at the Hanover Park experimental corn plots. These plots have received liquid sludge from 1968 through 1973

Constituent		MDL*	1968	1969	1970	1971	1972	1973
pH			7.0	7.5	7.7	7.7	7.8	7.6
Total P	mg/l	0.01	0.25	0.21	0.24	0.50	0.15	0.53
Cl^-	,,	1.0	10	13.3	11.6	18.0	27.3	23.8
$SO_4^=$	,,	1.0	246	156	167	136	119	87
N-Kjeldahl	,,	1.0	2.2	0.80	0.5	0.58	0.9	0.72
$N—NH_3$	,,	0.1	0.78	0.43	0.4	0.38	0.31	0.30
$N—NO_2+NO_3$	,,	0.01	0.07	0.11	0.34	0.33	0.24	0.34
Alk as $CaCO_3$	,,	1.0	355	337	323	317	268	302
EC	μmhos/cm		M.A.	928	729	695	649	669
K	mg/l	1.0	4.6	1.87	1.21	0.90	1.30	1.13
Na	,,	1.0	14.7	9.47	10.8	13.6	7.9	7.84
Ca	,,	1.0	177	112.9	91.7	88.0	81.5	80.1
Mg	,,	1.0	83.3	65.2	62.7	66.3	65.0	61.8
Zn	,,	0.1	14.3	2.23	0.55	0.64	0.20	0.12
Cd	,,	0.1	0	0	0.01	0	0.01	0
Cu	,,	0.01	0.53	0.04	0.07	0.08	0.09	0.09
Cr	,,	0.02	0.1	0	0.01	0.01	0.01	0.
Ni	,,	0.1	0.01	0	0.06	0.03	0.04	0.02
Mn	,,	0.1	0.47	0.22	0.21	0.21	0.23	0.19
Pb	,,	0.03	0	0	0.04	0.05	0.06	0.05
Fe	,,	0.1	35.7	10.60	15.0	19.1	14.1	15.0
FC†	per 100 ml	2		11	11	11	6	1

* MDL=minimum detection limit of laboratory.
† Geometric mean.

applied over a 2-year period. Fecal coliform content during the first year of sludge application was 11/100 ml but dropped to 1/100 ml by 1973.

The surface draining had overall increases in K, Na, Mg, Cu, Pb, Cl^-, Kjeldahl-N, NH_3—N, and NO_2+NO_3—N (Table 11). Fecal coliform content of surface runoff has reflected the annual sludge application. The field tile draining the lower end of the plots is overlain with only gravel. Comparing the quality of the surface drainage which includes only a small amount of groundwater leachate indicates the potential of soil and a growing crop for removing soluble chemical species. While the NO_2+NO_3—N concentration in surface drainage has risen steadily reflecting the nitrification of accumulated sludge, the NO_2+NO_3—N of groundwater has stabilized at 0.4 mg/l which is much less than tile drainage concentration in 1973. If the surface runoff from the plots were not now being returned to the wastewater reclamation plant, it would have been necessary to capture field runoff in a retention basin and hold it until water quality was acceptable for discharge to the stream draining the local watershed. Indeed this has been the practice in many land reclamation projects including the District's Land Reclamation site in Fulton County, Illinois.

TABLE 11. Average annual chemical and fecal coliform content of surface drainage collected weekly from a tile drain at the Hanover Park experimental corn plots from 1969 through 1973. These plots have received liquid sludge from 1968 through 1973

Constituent		MDL*	Year 1969	1970	1971	1972	1973
pH			7.6	7.7	7.6	7.8	7.6
Total P	mg/l	0.01	0.22	7.0	0.5	0.35	3.12
Cl^-	,,	1.0	40	42.6	111	118	81
$SO_4^=$	,,	1.0	156	192	148	101	36
N-Kjeldahl	,,	1.0	1.17	37.3	2.5	5.6	15.0
N—NH_3	,,	0.1	0.68	33.9	1.8	4.3	11.4
N—NO_2+NO_3	,,	0.01	5.46	10.0	5.46	6.35	21.8
Alk as $CaCO_3$	,,	1.0	346	377	433	360	388
EC	μmhos/cm		1048	1100	1232	983	1318
K	mg/l	1.0	1.04	1.60	1.5	2.3	5.58
Na	,,	1.0	18.4	17.3	43.6	42	35.7
Ca	,,	1.0	135.7	127	158	130	133
Mg	,,	1.0	50.6	59.5	72.8	65	65
Zn	,,	0.1	0.03	0.10	0.04	0.02	0
Cd	,,	0.01	0	0	0	0	0
Cu	,,	0.01	0.02	0.02	0.02	0.06	0.06
Cr	,,	0.02	0	0.01	0.02	0	0.01
Ni	,,	0.1	0	0	0	0	0
Mn	,,	0.1	0.32	0.16	0.42	0.28	0.26
Pb	,,	0.03	0	0.04	0.05	0.05	0.07
Fe	,,	0.1	5.70	4.98	4.27	2.1	2.45
FC†	per 100 ml	2	25	20	<15	32	41

* MDL=minimum detection limit of laboratory. All values less than these are reported as zero.
† Geometric mean.

Summary. Hanover Park Experimental Corn Plots

The Hanover Park experimental corn plots have received sludge every year from 1968 to 1973. After 6 years, total sludge application to these plots ranged from 107 to 203 metric tons dry solids/ha. Soils, ground- and surface-drainage waters, and plant leaves were sampled through the 6-year period and analyzed to note any responses to the sludge application.

While some of the major soil nutrients have decreased in control plots, the sludge fertilized plots have either maintained or increased the content of the soil parameters determined. Available phosphorus content of sludge fertilized soil was 5 to 8 times that of the control plots but stabilized in the sludge-fertilized plots. The uniform drop in soil pH (0.6 pH unit) of all the plots indicates that liming may eventually be needed.

Analysis of groundwater leachate indicated that the groundwater quality has improved as there has been an overall decrease in chemical content. Surface drainage had increased in N, P, and K concentrations in the same period. This showed that in some cases there is a need for field runoff catchment basins if the slope and/or soil texture so warrant. The difference in quality between groundwater leachate and surface drainage water demonstrates the ability of the soil and crop to remove soluble chemicals from infiltrating water.

Corn leaves were analyzed to determine relative uptake of metals between sludge fertilized and non-fertilized corn. The results have indicated increases in Zn, Mn, and Cu in plant leaves from sludge-fertilized plots. Corn grain analysis began with the 1973 crop to determine any increased metal input to grain due to sludge treatment. No response to sludge application was noted for the metals in the grain except for Ca. The largest response to sludge fertilization was a dramatic increase in corn yields for all 6 years. Corn yields were nearly doubled due to the nutrients and water from sludge fertilization.

Response of Vegetables to Sludge Fertilization

Some waste-treatment plant sludges contain higher concentrations of Cr, Zn, Cu, Pb, Ni, Hg, and Cd than are found in typical agricultural soils. Berrow and Webber (1972) reported the results from analyses of forty-two sewage sludges collected from rural and industrialized city wastewater treatment plants in England and Wales. On a dry-matter basis they found the sludges contained consistently greater concentrations of Ag, Bi, Cu, Pb, Sn, and Zn than are present in typical agricultural soils. In a small number of sludges, B, Co, Mo, Cr, and Ni were present in sludges at greater concentrations than found in typical soils. They correctly point out that the amount of trace elements present in soluble or available form is more important in relation to uptake by plants than is the total content. Thus, they assessed the solubility of several trace elements by extracting with 2.5% acetic acid. In Table 12 their extractability data and some of ours are presented by decreasing solubilities of several elements in soils. These data and others from our field studies confirm our earlier opinions that we must be mainly concerned with the first six elements presented in Table 12 when municipal waste are utilized as a fertilizer.

On the basis of total and extractable concentrations of trace elements in sludges, Berrow and Webber speculate that where sludges are used over a period of several years to

TABLE 12. Average concentrations of trace elements extracted by 2.5% acetic acid from forty-two sludges collected in England and Wales (Purves, 1972) and percent of total amount present that was extractable

Element	Mean extractable as ppm d.w.	Mean % soluble of total content
Cd*	144	65
Mn	300	56
Ni	190	46
Zn	1540	44
Co	8.8	32
B†	10	25
Cu	96	6.9
V	3	4.8
Cr	22	3.1
Fe	650	2.8
Pb	20	2.8
Mo	0.12	1.9
Sn	0.58	0.5

* Unpublished 0.1 N HCl data.
† Hot water extractable.

fertilize crops, some of the accumulating trace elements may give rise to toxicity problems in plants. From the results of chemical analyses of samples collected from soils contaminated with trace elements by air pollution and the use of municipal compost and sludges, Purves (1972) speculates that a "general enhancement of the level of potentially toxic trace elements in plants grown in urban areas could lead to deleterious effects both on the plants and on the health of those eating them". During 5 years of research using digested sludge, we have not yet created trace element toxicities in various feed grain and forage crops nor have levels of any element increased in plant tissues to the extent that they would present a hazard to animals consuming the produce. Furthermore, LeRiche (1968) analyzed soils and crops from a market garden experiment at Woburn, England, where 1278 t/ha of sludge had been applied between 1942 and 1961. While there was an increase in the uptake of some elements by vegetable crops grown on the sludge-treated plots, as can be seen in Table 13 from the average values of his reported results, he reported that there was no evidence that crop yields were affected.

TABLE 13. Availability of trace elements and their uptake by vegetable crops growing on a soil treated with 568 tons/acre of sewage sludge (LeRiche, 1968, Harpenden, England)

				Co	Cr	Cu	Mo	Ni	Pb	Zn
				ppm (dry matter)						
0.05 N HOAc extractable	Sewage 1958			—	4.5	18	—	51	3.5	750
	Sewage 1959			—	2.5	22	—	49	3.0	850
	Soil 1959	Treated		—	2.8	20	—	17.5	5.0	395
	Soil 1959	Untreated		—	0.5	5.0	—	4.3	1.2	87.5
Total contents	Leeks 1960	Treated		0.16	0.54	15.0	1.10	6.95	1.60	135
		Untreated		0.18	0.71	5.75	0.50	2.0	1.15	46
Total contents	Globe beets 1960	Treated	Top	<0.1	1.0	10.0	0.7	16.5	2.6	510
		Untreated	Top	<0.1	0.9	9.0	0.5	3.2	2.4	219
		Treated	Root	<0.1	0.8	18.0	0.3	13.0	1.6	250
		Untreated	Root	<0.1	0.3	11.0	0.1	1.7	0.9	130
Total contents	Potatoes 1961	Treated	Top	0.35	3.00	8.3	0.98	5.25	2.60	270
		Untreated	Top	0.38	1.70	4.3	0.38	1.70	2.80	90
		Treated	Root	0.02	0.03	9.5	0.28	0.58	0.19	28
		Untreated	Root	0.03	0.09	9.5	0.40	0.25	0.25	30
0.5 N HOAc extractable	Soil 1967	Treated		—	2.6	58	—	8.1	4.2	275
		Untreated		—	0.9	14.5	—	3.4	1.6	84
Total contents	Carrots 1967	Treated	Top	<0.08	0.88	9.9	0.85	3.00	1.7	99
		Untreated	Top	0.06	0.41	8.2	0.58	1.14	1.09	48
		Treated	Root	<0.05	0.07	4.6	0.12	2.00	0.07	42
		Untreated	Root	<0.05	0.03	6.3	0.13	1.45	0.06	34

The behavior of such trace elements in soils and their uptake by crop plants are influenced by several factors. One of these is soil pH. Most heavy metal toxicities in terrestrial plants have been associated with pH values of less than 5. Liming soils can, to a large extent, control the uptake of many trace elements.

Practices which promote better soil aeration, such as drainage and structure development, may lead to decreased solubilities of some trace elements. According to Jenne (1968)

oxides of iron and manganese act as "sinks" for heavy metals and the extractability or leachability of the metals is determined by the Eh (reduction-oxidation potential) and pH of the system. Keeping the Fe and Mn hydrous oxides in soils and sediments in the form of thin coatings on silicate minerals instead of discrete crystalline minerals permits a chemical activity in far greater proportion than would be expected on the basis of their concentrations alone. As the solubilities of iron and manganese compounds are increased by reducing conditions, the heavy metals originally adsorbed on the surfaces of their oxides are displaced by hydrogen and the metals become more mobile in soils.

Some heavy metals may form inert and insoluble compounds with clays and organic compounds. Thus, many trace elements are less available to growing plants than the total concentrations of these elements would indicate.

When grown on the same soils, tissues from different crop species, and even different varieties of the same species, differ markedly in concentrations of nutrient and pollutant elements. The selection of crops or even varieties of a particular crop species thus affords a control over the entrance of undesirable amounts of trace elements into food chains. With regard to selection, Gabelman (1970) says: "The ease of discovery of these genetic differences within species has been surprising. We have been too conservative in assessing this potential."

Perhaps we have not observed trace-element toxicities in plants by the use of stabilized sludge because it may contribute toward establishing a better balance of nutrient availability and uptake by crop plants. We have learned from greenhouse and other studies that there are many synergistic and antagonistic interactions between various ionic metal species in sludge and soils affecting the absorption of chemical elements by plant roots and their translocation within plants. As we learn more about interaction effects, we may be able to decrease abnormal uptake of one trace element from soils by supplying another to the soil or crop.

Clearly if or when a trace element problem does occur as a result of utilizing municipal sludges as a fertilizer and/or soil amendment, there are management practices available which can be introduced to alleviate the situation. Except perhaps in coarse sandy-textured soils, the heavy metals will move very little with percolating water. Thus, most of the trace elements will remain at the point of application unless they are transported away in an adsorbed phase on eroded sediments. By establishing erosion control structures and practices, complete control can be maintained over all elements applied on land as a constituent of sludge except some anion and anion forming species such as nitrate, sulfate, chloride, borate, etc. At any rate, those chemical elements which present the greatest potential hazard to animals will be retained in place and can be managed if the need develops. To a large extent the opportunity to manage trace elements is lost once they are disposed of in water environments like the ocean or in air by incineration, or by storing ash residues in landfills where they can be leached by percolating water.

Effect of Sludge Application on Acid Mine Spoils

Successful reclamation of both acidic and calcareous mine spoils has been accomplished with liquid anaerobically digested sludge. Early experiments wi[illegible] acidic [illegible] spoils demonstrated the potential of digested sludge application for u[illegible]

Acidic mine spoils are some of the most difficult of all disturbed lands to reclaim. Chemical barriers such as low pH and high exchangeable Al are only slowly removed by natural means and very effectively prohibit the establishment of nearly all types of vegetation. The low pH usually results from pyrite (FeS_2) oxidation to sulfuric acid. This acidity solubilizes additional compounds, especially metallic compounds, some of which may be present in phytotoxic concentrations. In contrast to the elevated metal concentrations, acidic mine spoils are usually deficient in the major plant nutrients (N, P, K, Ca, and Mg).

Acidic spoils require pH control and fertilization for the successful establishment of vegetative cover. Once established, the plant life will help maintain and improve the spoil material by erosion control and through bio-cycling of essential plant nutrients and formation of humus.

The U.S. Forest Service has recently become involved with spoil reclamation of the Palzo Mines in Southern Illinois.* This acidic mine spoil, now a part of the Shawnee National Forest, has had virtually no vegetation since surface mining ceased in 1961. The acidic runoff has seriously affected a nearby receiving stream (Sugar Creek) and the solution of this problem has become the Forest Service's primary goal.

Two feasible methods chosen were liming and incorporation of liquid digested sewage sludge. Field evaluation was done with test plots treated with lime or digested sludge and planted to grasses. Although both types of treatment resulted in germination and growth of the grasses, sludge produced a more vigorous growth while improving subsurface drainage-water quality. The Forest Service has reclaimed 15 acres (6 ha) of spoil with lime and inorganic fertilizer. They plan to reclaim 192 acres (77.8 ha) of the spoil by treating with digested sewage sludge. The test plot results indicated that a minimum-maximum limit of 200–250 dry tons of sludge/acre (448–560 dry metric tons/ha) should be applied. Table 14 presents a partial analysis of a lagooned digested sludge. An overhead sprinkler irrigation system will be used to apply 1 inch of liquid sludge per week. When dry the solids will be disced into the top 9–12 in. (23–30 cm) during the application period to help increase infiltration and check erosion. Subsurface water will be continuously monitored before, during, and after sludge application.

TABLE 14. Analysis of lagooned digested sludge from The Metropolitan Sanitary District of Greater Chicago (Peterson *et al.*, 1971)

Constituent	Average conc.	Constituent	Average conc.
	% dry basis		% dry basis
Total N	2.6	Cd	0.05
NH_4—N	1.2	Cr	0.38
Total P	3.4	Cu	0.22
K	0.36	Na	0.28
Ca	2.1	Ni	0.05
Mg	0.97	Pb	0.08
Zn	0.98		
Fe	3.4	pH	7.2
Mn	0.02	EC	3.9 μmhoscm

* Palzo Restoration Project, Final Environmental Statement, Shawnee National Forest, Forest Service, U.S. Department of Agriculture, July 15, 1972.

As a further contribution to the Forest Service's efforts, the Metropolitan Sanitary District of Greater Chicago supplemented their test plot experiments with a laboratory column study. Columns of acidic spoil material from Palzo Mines (Table 15, line 1) were treated with liquid sludge (Table 14) and then leached daily with aerated deionized water for 110 days.

TABLE 15. Constituents leached in 110 days from columns containing 2-kg acidic spoil material treated with varied amounts of lagooned digested sewage sludge (Peterson and Gschwind, 1972)

	Constituents leached from columns in 110 days										
Column*	Total Acidity†	NH_3—N	SO_4	Zn	Al	Mg	Ca	Fe	P	Soluble salts	pH
					mg					μmhos/cm	
1	2238	14.7	3047	4.9	138.0	18	383	230	1.69	2.03	2.43
2	2868	475.0	7311	3.0	1.8	418	1439	263	19.74	1.88	6.20
3	5048	334.0	4911	5.0	148.0	67	240	401	1.83	2.07	2.62
4	1855	263.0	4542	100.0	2.0	166	1183	45	16.63	1.19	4.96
					Normalized						
1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	—
2	1.28	32.31	2.40	0.61	0.01	23.35	3.76	1.14	11.69	0.93	—
3	2.26	22.72	1.61	1.02	1.07	3.74	0.63	2.18	1.08	1.02	—
4	0.83	17.89	1.49	20.41	0.01	9.27	3.09	0.20	9.84	0.59	—

*Column 1: control, 2-kg acidic spoil material.
Column 2: homogeneous mixture, sludge equiv.=122 metric tons/ha.
Column 3: top quarter sludge treated, sludge equiv.=61 metric tons/ha.
Column 4: homogeneous mixture, sludge equiv.=61 metric tons/ha.
†As $CaCO_3$.

The laboratory results substantiated the field observations. These results indicated that sludge treatment can raise the leachate pH (Fig. 2). A reduction of the total acidity, soluble salts (EC), and soluble Al and Fe concentrations was observed with the complete incorporation of 61 metric tons sludge/ha (Table 16, column 4). Analysis of the treated spoil material

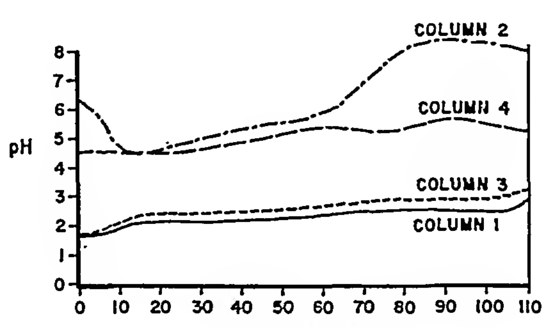

Fig. 2. The pH of the leachate from sludge-treated acidic spoil material during 110 days of daily leaching with aerated deionized water. The treatments were: column 1—no sludge; column 2—sludge equivalent to 122 metric ton solids/ha mixed; column 3—sludge mixed in top quarter equivalent to 61 metric tons solids/ha; column 4—sludge equivalent to 61 metric tons solids/ha mixed (Peterson and Gschwind, 1972)

TABLE 16. Chemical and physical characteristics of an acidic mine spoil treated with liquid digested sewage sludge before and after leaching for 110 days

Column*	Spoil depth, cm	0.1 N HCl extractable					Avail. P	Exchangeable				EC μmhos/cm	1/3 Bar water, %
		Fe	Mn	Zn	Cu	Cr		CEC	Ca	Mg	NH_4—N		
		μg/g						meq/100 g					
Unleached	spoil	1683	8.0	54.3	14.0	4.3	16.8	12.6	1.69	0.39	0.08	2000	—
1	0–10	2260	3.5	28.0	6.2	3.5	15.4	12.7	0.78	0.11	0.11	0.185	26.20
	10–20	1630	4.1	103.0	6.2	3.4	17.5	12.6	1.18	0.44	0.11	0.287	26.72
	20–30	2595	20.6	542.1	127.1	66.7	17.5	12.8	1.28	0.26	0.12	0.319	26.79
	30–40	2183	9.7	318.7	72.4	47.6	14.7	12.8	1.00	0.51	0.08	0.373	28.12
3	0–10	1405	3.5	90.2	6.1	3.2	280.0	18.1	10.71	4.52	0.13	0.513	34.23
	10–20	2184	10.4	220.1	69.9	48.2	86.1	14.0	4.29	2.36	0.11	0.207	28.30
	20–30	3820	37.4	1251.0	248.9	178.9	16.1	12.3	1.95	1.10	0.14	0.385	27.72
	30–40	2489	19.7	645.6	130.4	84.6	14.7	13.5	1.40	0.51	0.19	0.476	27.61
4	0–10	1574	7.7	136.4	33.3	19.6	149.1	14.9	5.01	2.04	0.24	0.160	30.43
	10–20	1492	3.5	144.7	5.5	3.5	143.5	14.7	5.07	1.88	0.29	0.083	30.15
	20–30	2062	20.7	555.9	125.7	76.6	143.5	14.0	4.96	2.05	0.34	0.150	31.05
	30–40	2184	19.2	488.5	126.8	77.6	143.5	14.5	4.71	2.11	0.41	0.136	31.37
2	0–10	2419	11.7	403.6	79.8	52.1	322.0	15.4	7.24	4.27	0.16	0.144	31.85
	10–20	2542	10.0	206.5	67.4	51.0	343.0	16.0	7.63	3.83	0.40	0.159	32.18
	20–30	1597	5.5	112.7	7.1	5.2	322.0	16.1	5.99	3.59	0.82	0.185	31.89
	30–40	1935	3.8	70.4	6.4	3.8	231.0	15.9	7.44	3.69	0.88	0.309	31.58

*Column 1: control, 2-kg acidic spoil material.
Column 2: homogeneous mixture, sludge equiv.=122 metric tons/ha.
Column 3: top quarter sludge treated, sludge equiv.=61 metric tons/ha.
Column 4: homogeneous mixture, sludge equiv.=61 metric tons/ha.

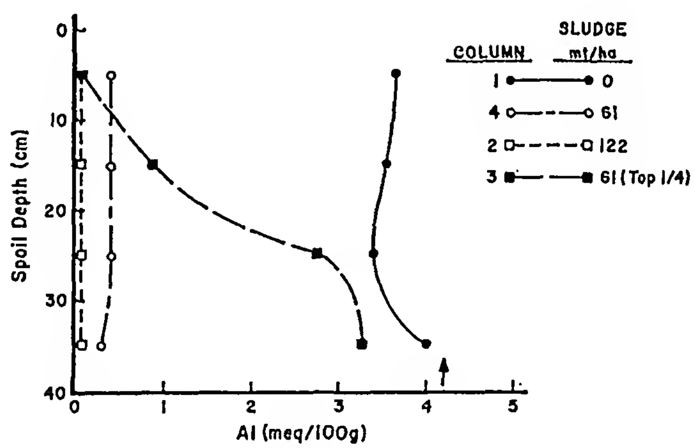

Fig. 3. The exchangeable Al concentration of sludge-treated acidic spoil material after leaching daily for 110 days with deionized water. The arrow indicates the exchangeable Al of unleached untreated acidic spoil material.

(Table 16) showed that general fertility was increased while phytotoxic concentrations of Al (Fig. 3) and adverse pH (Fig. 4) conditions were eliminated. The increased water-holding capacity and tilth of the sludge-treated spoil material demonstrated that sludge is also a

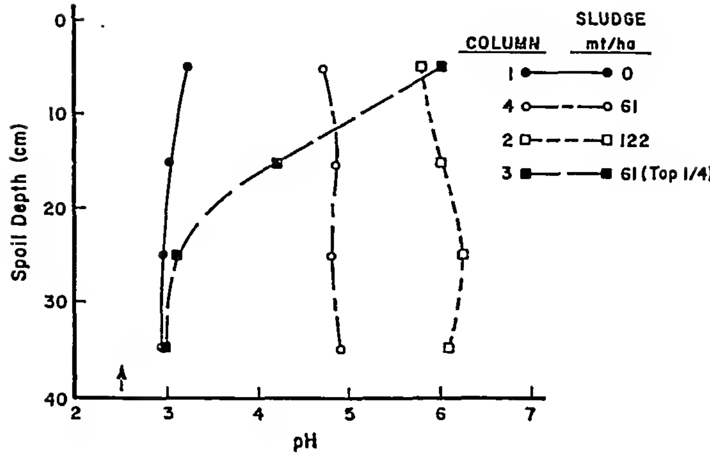

Fig. 4. The pH of sludge-treated acidic spoil material after leaching daily for 110 days with deionized water. The arrow indicates the pH of unleached untreated acidic spoil material.

soil conditioner. It was observed during the leaching experiment that the sludge-treated spoil material absorbed water much faster than untreated material probably due to the-aggregation caused by sludge treatment. This would lessen surface runoff and its con comitant detrimental effects on receiving land and waters.

Effect of Sludge Application on Strongly Alkaline Soil

Although sludge treatment can reduce acidity problems of mine spoils, it can also reduce severe alkalinity problems. In 1969, sludge supplied by MSDGC was used to treat an alkali sand-filled lagoon (pH 10.5) near Ottawa, Illinois, which was owned by the Libbey Owens Ford Glass Company. The sludge was incorporated into the sand by filling 2-foot deep trenches with liquid sludge and then covering with the sand. Using this application method 170 dry tons of sludge/acre (381 metric tons/ha) were mixed into the sand surface. Grass was planted and has grown vigorously ever since. The area is now a part of a wildlife refuge.

Effect of Sludge Application on Calcareous Soils

Presently, MSDGC is concentrating its land reclamation program in the coal-mine spoils of Fulton County, Illinois. Encouraged by the results of the efforts described above, the Fulton County project is the first large-scale operational reclamation program of mine spoils undertaken by MSDGC. As of October 1972, over 13,000 acres (5265 ha) of spoils had been purchased in Fulton County by MSDGC.

The Fulton County spoils are calcareous and while they do support some vegetation, they are rather infertile and low in organic matter. Nitrate and exchangeable ammonium profiles (Figs. 5 and 6) of mine spoils and undisturbed land on this site showed the extent of natural restoration 10 years after mining ceased. Figure 6 indicates that there is an exchangeable NH_4 reserve of only 14 lb of N/acre (31.4 kg N/ha) in the plow layer (0–6 in.) of the spoil material. At the time of the borings (February 1971) there was only 3.6 lb of

NO_2+NO_3—N/acre (4 kg N/ha) in the plow layer. Organic carbon for the surface layer averages <0.5% so organic nitrogen reserves are low.

The low nitrogen and organic matter of these spoils should rapidly be alleviated by treatment with sludge. Continued soil testing will determine how rapidly the mine spoils are upgraded by sludge. Plant tissue analysis will be used to verify that crops are receiving enough nutrients.

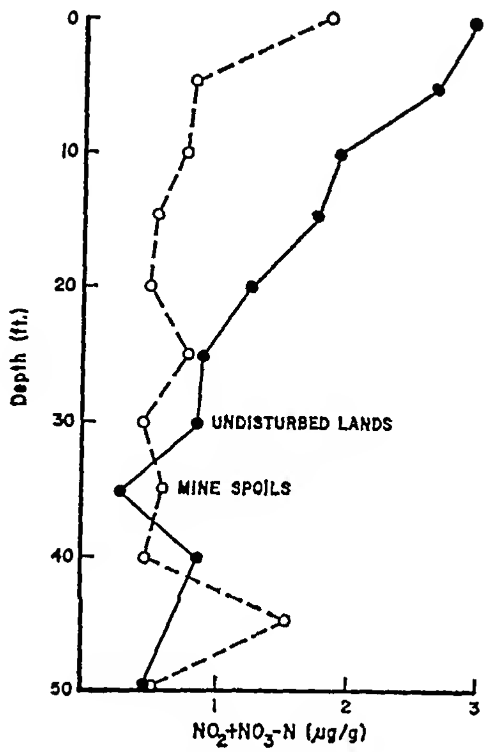

Fig. 5. The average nitrite and nitrate-N of soil cores collected in February 1971, in Fulton County, Illinois, prior to the application of sludge.

While the objective of the Fulton County program is the utilization of sludge on mine spoils, sound ecological practices remain the guideline. Fields developed from spoils are surrounded by berm structures and sloped toward retention basins so that all runoff can be collected and the quality checked before eventual discharging. In the event that the water does not meet standards, it can be held or pumped back onto the fields. Nutrient barriers surrounding the existing lakes and waterways provide further protection of water quality. Monitoring wells are strategically placed to carefully observe ground water quality; lakes and stream waters are also sampled. Thus, background data has been established for water quality before sludge application.

The sludge to be used is barged down the Illinois River to Liverpool, Illinois, where an 11-mile (17.7 km) pipeline takes the sludge to huge 5000 acre-foot storage basins (6.2×10^6 m^3) on the site. A dredge and pipeline system is used to transport the sludge to high-pressure traveling central pivot gun sprayers for application on the constructed fields. Extensive testing of the effects of sludge fertilization on soil, plant, and water by the University

of Illinois Agronomy Department (Hinesly, Braids and Molina, 1971; Hinesly, Jones, and Ziegler, 1972), and MSDGC's own research demonstrated the beneficial results possible by using sludge and have established important guidelines for the use of sludge on land. Nitrogen was determined to be the limiting factor in application rates. This factor is based on soil, climate, and crop conditions which will not result in nitrate pollution of ground water.

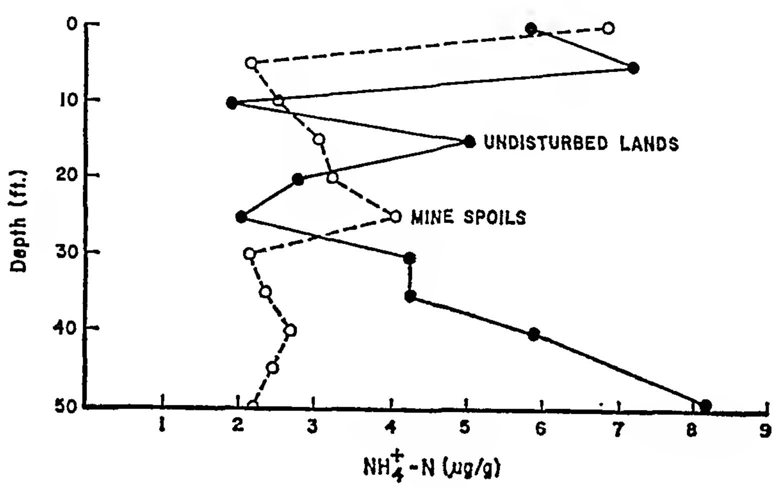

Fig. 6. The average exchangeable NH_4^+—N of soil cores collected in February 1971, in Fulton County Illinois, prior to the application of sludge.

Certain modifications are possible on regraded spoil land, and high fertilizer rates will be used initially to ensure an early vegetative cover which will minimize silting losses. These high rates were determined from careful consideration of the type of spoil material and are not expected to cause nitrogen pollution of ground water. The spoils in Fulton County are calcareous and the textures range from loam to clay loam. The 30–60 ft (9–8 m) of overburden has an average pH of 7.7 which was partly due to the mixing of 1–2 ft (30–60 cm) of St. David limestone throughout the overburden. The mining operation also mixed 4–60 ft (1.2–18 m) of Canton shale throughout this profile. This is a calcareous shale. White (1959) reports Canton shale as 30% clay of which 40–70% was illite. The ability of illite as well as other micas and micaceous clay minerals to fix K and NH_4 was described by Nommik (1965). The equilibrium is as follows:

$$\underset{\text{soluble}}{(NH_4+K)} \rightleftarrows \underset{\text{exchangeable}}{(NH_4+K)} \rightleftarrows \underset{\text{fixed}}{(NH_4+K)}$$

Continued additions of NH_4 as well as the alkaline soil drive these reactions to the right. The reaction of

$$\underset{\text{fixed}}{(NH_4+K)} \longrightarrow \underset{\text{exchangeable}}{(NH_4+K)}$$

is strongly hysteretic, Nommik (1965). Sewage sludge is low in K (*ca.* 0.3% on a dry basis). Dhariwal and Stevenson (1958) reported that the A, B, and C horizons of an Elliott soil had 80, 65, and 65% illite and it had a total fixed NH_4 of 0.99, 1.98, and 2.63 meq/100 g, respectively, in the top three horizons. The Elliott C horizon is similar to the land in Fulton

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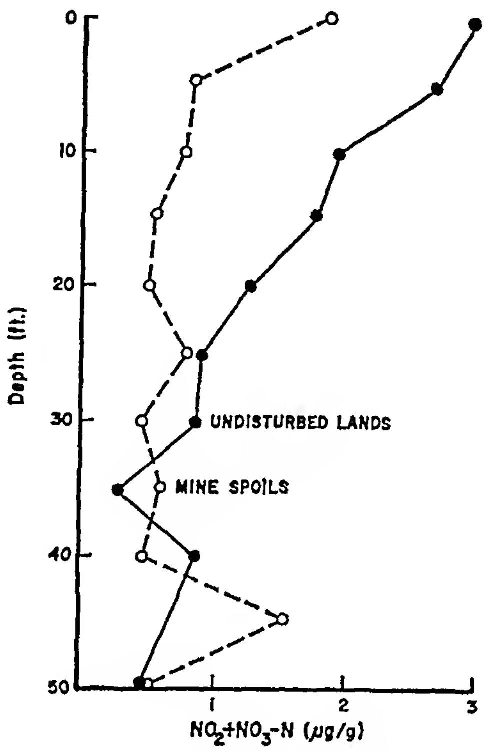

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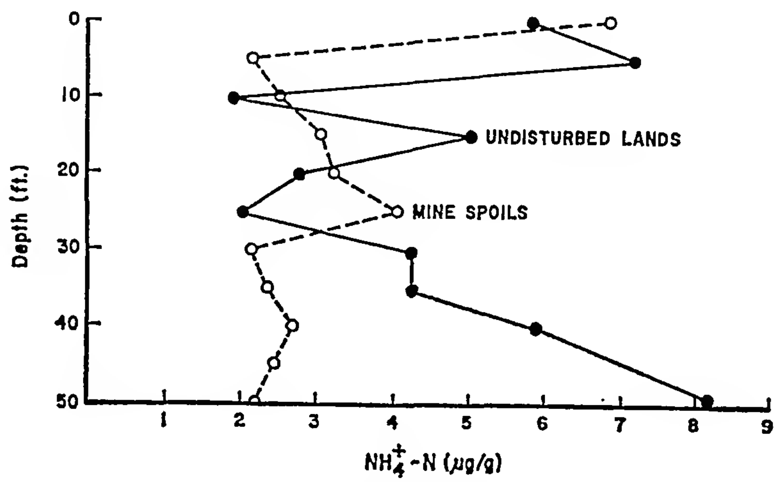

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County. This indicates that approximately 1400 lb of NH_4—N may be fixed in 1 acre-foot of this type of material.

Crop removal of nitrogen varies with the crop. For corn, nitrogen removal from the field in the grain averages 0.77 lb per bushel (9.9 g/l) of grain (Boone and Welch, 1972).

Nitrogen is also lost by volatilization of ammonia from the soil surface. When sludge is applied to a soil surface, most of the ammonia volatilization occurs during drying. This loss may amount to 50% of the applied ammonia.

The sludge application rates for the first 5 years were based on the above considerations. These rates decrease with each succeeding year as the fertilizer and crop residuals accumulate in the spoil material. Mineralization of these increasing residuals to produce NO_3—N becomes more significant with each passing year.

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Chapter III

EFFECTS OF RECYCLING OF WASTES ON NON-RENEWABLE RESOURCES

CONTENTS

IMPLICATIONS OF SOLID WASTE MANAGEMENT ON NON-RENEWABLE RESOURCES

EARL T. HAYES

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The potential impact of recycling on non-renewable resources relates to three distinct areas: energy, metallic minerals, and non-metallic minerals. That order signifies not only the importance in today's society, but also the relative significance of impact from recycling. Briefly, recycling can achieve energy savings through materials recycling; it can achieve energy savings through the generation of fuel; it can accomplish ore or virgin material savings; it can accomplish capital savings (which relates to more material and energy savings); and most importantly, it can accomplish a reallocation of resource use, so that virgin materials are used for the highest tolerance or most valuable end products.

In order to obtain a perspective on this situation, let us first look at what are the constituents of an incoming ton of urban solid waste. According to the Final Report of the U.S. National Commission on Materials Policy, the solid waste collected annually includes 30 million tons of paper and paper products, 4 million tons of plastics, 100 million tires, 30 billion bottles, 60 billion cans, millions of tons of demolition debris, grass and tree trimmings, food wastes, and millions of discarded major appliances. On a percentage basis organic refuse, including paper and plastics, constitutes about 70% of solid waste. Glass and ceramics constitute about 10% of municipal solid waste. Ferrous products constitute another 8%; aluminum and other non-ferrous metals make up between 1½ and 2%. Interestingly enough, however, it is the metallic fractions which have the lowest volume that have the most resale value and the organic or energy fractions which have the lowest value and the largest bulk.

Dissecting the effect of recycling on non-renewable resources involves looking at each of the five categories of economic impact. This means that we should start with energy savings from the recycling of materials. According to a report entitled, "Energy Expenditures Associated With the Production and Recycle of Metals", published by the Oakridge National Laboratory it requires but 5% of the energy spent to produce virgin aluminum in order to produce the same aluminum from waste aluminum. In the area of iron and steel or ferrous metals, the factor is 25%. The Glass Containers Corporation has run its furnaces with 100% color or waste glass and achieved a 15–20% savings in energy expended according to Mr. Pickett Scott. Similar savings can be achieved in other materials.

This led the National Commission on Materials Policy to conclude that recycling of available materials could accomplish a 2% energy savings from recycling or some 386 billion kilowatt hours equivalent. Such energy savings thermodynamically could be considered an entropy saving or conservation of energy. There is a second type of energy

they cannot identify the different aluminum alloys or steel alloys. They cannot economically sort glass by color, and they cannot sufficiently eliminate all of the grease and all of the contaminants from all of the paper. Thus, there is resource degradation. The aluminum industry has demonstrated this with its specifications for alloys 3004, 3105 and recycled products. The most obvious example is the fact that much recycled material ends up in cast metals, rather than wrought metals.

While degradation of materials is a limitation on recycling, it need not be considered a serious one. The virgin resource industry can capitalize on recycling to restrict the use of virgin ores for their highest and best use. Let me give you an example. Plastics incinerated contain 19,000 Btu's per pound. That is about equivalent to oil. The implication of that statement is that crude oil and natural gas can be directed into plastics and petrochemicals, whose market value is some 15 times the market value of petroleum products as energy. The petroleum products, after being made into petrochemicals and plastics, can then be recycled into energy through incineration, pyrolysis, or hydrogenation. Some petroleum products cannot be recycled. These include fertilizer products which have raised corn yields per acre by two-thirds and permitted the world to feed a larger economy. Obviously, feeding people is as valuable or more valuable than driving a second or third automobile in a family. Thus, oil—the life of petroleum—can be extended by directing its use towards petrochemicals and by making up the deficit with coal and synthetic fuels and nuclear power. The recycling can then accomplish releasing the contained Btu's in the plastics and petrochemicals, so that the energy value of the oil is restored rather than lost.

Similarly, virgin aluminum can be used for its most pure or most valued properties. Recycled aluminum makes good can body stock and also good castings. In the area of steel detinning can be used to create number one scrap bundles whereas incinerated tin cans or tin plate steel becomes alloyed and loses some value. Its uses are restricted, but it makes little sense to use virgin ore to produce rebar angle iron or other low-tolerance metals. It has been demonstrated by the U.S. Bureau of Mines that recycled steel stands up well in performance tests against conventional steel. Thus, virgin ore can be directed to the BOF furnace or toward the production of high-tolerance stainless alloys, high carbon or tool steels, and other type specification products. Similarly, the use of glass, the use of glass sands to make flint glass, the use of *cullet* to make colored glass, and the use of cullet to make construction products such as brick and concrete block and paving can be envisioned. This reallocation of resource can extend the life of scarce virgin ores. While this is the least specific in terms of numbers, it is perhaps the most valuable concept which can be created by recycling in terms of a favorable impact on non-renewable resource.

In conclusion, a review of the second law of thermodynamics or energy conservation can be seen as a savings throughout all five of the specific types of impacts which recycling can have on non-renewable resources. From an entropy point of view, it has been said that the earth loses energy perpetually and could take itself into the dark ages by the perpetual consumption of energy. Therefore, all measures to save energy (including the savings of capital investment) are most valuable. Certainly energy savings by recycling material and by fuel generation are specific points. The reduction in the need to mine and process virgin materials creates a tremendous savings of energy. The reduction in the investment in the reduction of ores and production of primary processes and the reduction in both investment and operation of pollution-control facilities produce no product; they are a non-productive investment which requires energy to build and energy to operate. Therefore, any process which

DISCUSSION

McKELVEY: I wonder if Dr. Hayes can tell us what some of the obstacles seem to be in recycling? The arguments in favor of it seem so overpowering that one would think it would be practised to a far greater extent than it is. I wonder what seems to be the reasons for the delays in pursuing it?

HAYES: I am probably the lesser of all these fine experts on this platform, Dr. McKelvey. In my mind, there has been a certain amount of foot dragging. But in summation, at the present time, I see few obstacles to this. This is simply a way of life and we have accepted it. I think you will see as the morning goes on, that the economics now favor this complete recycle. Here and there, we are still wasting a lot of material. I don't deny this at all. Someone else want to try that?

You will see from the papers this morning that there are so many pilot plants, so many demonstration plants, so many operating plants now gathering data that we are past the stage of experimentation and we are now pursuing pure engineering economics. That is the theme of the morning's session. It's no longer theory or something that must be done. It *is* being done. And the data you will see presented this morning will demonstrate that we are on that last lap of determining the optimum process which, like mining, will have to fit any particular situation.

ROSENSHEIN: If you ever had an opportunity to watch a landfill operation, you'd see that the problems are really a lot more basic than just the aspect of being able to recycle. The whole concept of management of a landfill has to come into play too. Because the materials come in totally mixed, the manner in which they're handled and so forth really does not lend itself very effectively for any type of organized approach to recycling. This is a real basic problem in itself.

BERMAN: Un autre point méritant d'être souligné est qu'en France au moins—je pense que c'est aussi vrai aux Etats-Unis—jusqu'il y a très peu de temps, les industriels ne s'intéressaient pas à leurs déchets. Ils avaient suffisamment de problèmes avec ce qu'ils considéraient comme leur métier, c'est-à-dire produire d'une part, et vendre d'autre part; dès qu'ils avaient trouvé une solution satisfaisante pour se débarrasser de leurs déchets, pour ne plus avoir à penser à ce problème, ils étaient contents. La situation était la même dans la plupart des Municipalités: sauf quelques cas particuliers, les Maires veulent se débarrasser du problème des ordures, mais ils sont indifférents sur la méthode, sur ce que l'on fera avec.

D'autre part je voudrais poser une question: il me semble qu'une des raisons pour lesquelles l'emploi du pétrole est devenu si important—en particulier par rapport au charbon—est que le pétrole est liquide, et que tous les produits pétroliers utilisés classiquement comme combustible sont également liquides. Est-ce que transformer le pétrole en matières plastiques, puis récupérer l'énergie des matières plastiques, ne risque pas de faire disparaître cet avantage de facilité d'emploi, et donc d'être difficile à appliquer, ou même peu intéressant dans certains cas?

KEILING: J'ai peut-être par rapport à beaucoup d'entre vous l'avantage d'avoir vécu la guerre et la disette européenne qui en est resultéé. Brusquement, vers le 18 juin 1940, l'Europe est passée d'une période de pléthore à tous égards à une période de disette quasi instantanée. A ce moment-là, la pollution s'est effacée car tout ce qui était rejet de la période de pléthore est devenu utile dans la période de disette. On a vu se ruer tous les Européens sur ce qu'ils négligeaient quelques mois auparavant. C'est une leçon historique que nous avons vécue à quelques-uns, les anciens, mais je crois qu'il serait utile de s'inspirer, au point de vue du recyclage, à tous égards, de la matière organique comme de la matière minérale, des leçons de cette période. Je m'excuse de dire cela à nos amis d'Amérique du Nord qui n'ont pas connu ces temps difficiles. Mais pour nous, nous ne sommes pas du tout surpris de ce qui se passe actuellement. En 1940, il n'y avait plus de sous-produits, plus de rejet, pratiquement plus de pollution.

HAYES: We still not have answered Mr. Berman's . . .

PARIZEK: Another comment . . . perhaps why recycling has been slow to be adopted in the United States as I see it. In the state of Pennsylvania we have many large metropolitan areas that create large volumes of waste. These communities are left with the impression that the technological advantages of recycling still do not exist, the economics of it are still not of benefit to them. So they go to land disposal in what are called sanitary landfills under the assumption that landfills are cheaper, that it's a cheaper way for the moment to get rid of their problem—whether it's a large city or a small city. The realities of burying waste, as we study these in detail, show us that there is a leachate problem associated with it which can bring about a serious pollution, although the word sanitary landfill implies no adverse effects to the environment. The leachate problems, when investigated in detail, can cause serious damage to the groundwater supplies of an area. If you add now the cost of that leachate problem, you may find that land filling is not as cheap as some people were originally led to believe. Our research shows us that the landfill costs are going to be greatly increased as soon as you look at the leachate problem and try to solve it. We have leachate being generated maybe for 10, 20, and maybe as much as 100 years from large sanitary landfills. The quality of water is worse than that of raw sewage. The damage that this can cause to aquifers in a given area will greatly increase the cost. As an example, right now in one municipality where a lawsuit of $2 million has been or soon will be taken on a group who maintained a landfill at the county level, a great amount of damage to an aquafer system and the cost of repairing the damage is immense in that example.

LES INDUSTRIES DE RÉCUPÉRATION DES REJETS SOLIDES EN FRANCE : EXEMPLES ACTUELS ET CARACTÈRES GÉNÉRAUX

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L'élaboration d'un produit fini à partir d'une matière brute passe généralement par les trois stades successifs d'extraction, de transformation, de consommation qui sont chacun générateur de déchets divers. Ces déchets doivent être évacués, soit par abandon au milieu naturel, soit au contraire par réintroduction dans les processus industriels de fabrication qui les valorisent.

Sous ce dernier aspect, quels sont les faits les plus marquants de la récupération industrielle des rejets solides en France à l'heure actuelle?

Au niveau des industries extractives, d'abord, on estime que par an les mines produisent environ 42 millions de tonnes de déchets et les carrières environ 75 millions de tonnes (Groupe d'études, 1973). Une grande partie est ajoutée aux remblais déjà existants, mais, dans certaines régions, la raréfaction des sites de stockage, l'augmentation des charges du stockage lui-même, l'épuisement des gisements de matériaux traditionnels ont amené à reconsidérer la question.

Les Houillères du Bassin du Nord et du Pas de Calais, par exemple, qui disposent de plus de 500 millions de tonnes de schistes houillers en terrils, et chaque année d'environ 10 millions de tonnes de schistes d'extraction ou de lavage, ont recherché la valorisation de leurs stériles dans trois directions (Hanquez, 1973):

— la vente en l'état du schiste tout-venant, comme matériau lourd de fondation et stabilisation (700 000 tonnes en 1970);

— la vente après calibrage des schistes rouges, pour la décoration des espaces verts, le revêtement et les fondations de voies de circulation (500 000 tonnes en 1970);

— la fabrication de granulats légers artificiels de densité et dimension variables selon les usages: pour répondre en partie aux besoins potentiels de la région parisienne et du nord de la France estimés à 1 million de m^3/an d'agrégat léger, une usine de 1 000 m^3/j de capacité sera opérationnelle au début de l'année 1975.

Autre exemple similaire, celui de l'utilisation des sous-produits d'exploitation du minerai de fer lorrain (Deschryver, 1972): une société filiale de la société USINOR a déterminé que les caractéristiques chimiques et granulométriques de ses rejets permettaient de les écouler directement comme matériau de confection de routes, de drains ou de canalisation, comme correctif chimique en cimenterie, comme substitut du sable à béton. Elle a même cherché

à fabriquer des produits dérivés élaborés, tel le "stérile-laitier", mélange de stérile tout-venant, laitier granulé, chaux grasse, proposé pour les couches de fondation de chaussées. Ainsi, grâce à cet effort de promotion technique et commerciale, 700 à 1000 t/j de rejets trouvent un débouché dans divers secteurs d'activité.

Dans un cas comme dans l'autre, l'utilisation des rejets d'extraction offre les mêmes particularités: elle est géographiquement limitée aux régions où des contraintes de stockage d'ordre économique et écologique s'ajoutent à des besoins d'approvisionnement en matériaux bon marché de grande consommation. Elle commence alors à se développer dans un cycle court de production dont la mise en place nécessite:

- une connaissance minimum des propriétés des matériaux à écouler (granulométrie, densité, porosité, composition chimique . . .);
- un traitement simple préalable adaptant la qualité à la demande (homogénéisation, préparation mécanique) et facilitant les reprises (stockage, manutention).

Elle peut enfin évoluer vers des applications plus élaborées suivant la découverte de possibilités nouvelles offertes non seulement par les produits mais encore par le marché.

Au niveau des industries de transformation, la diversité des activités est si grande que les quantités de déchets correspondantes sont très mal connues. Différentes opérations de recensement laissent supposer une valeur supérieure à 7 millions de tonnes et probablement proche de 11 millions de tonnes, dont environ les 2/3 seraient des déchets solides (Groupe d'études, 1973).

Dans ce domaine, la récupération intervient de deux manières: d'une manière spécifique au type d'industrie d'abord, d'une manière spécifique au type de produit ensuite.

Le premier cas peut être illustré par des exemples empruntés à l'industrie chimique, à la sidérurgie, à l'industrie énergétique.

L'industrie chimique est typique d'une activité de transformation pour laquelle la production de déchets est inévitable: la plupart des réactions chimiques en effet utilisent plusieurs sortes de matières premières, mais fournissent des composés parmi lesquels, le plus souvent, un seul est nécessaire à la suite des opérations.

C'est ce qui se passe dans l'attaque des phosphates tricalciques naturels par l'acide sulfurique, où la réaction donne, associée à l'acide phosphorique, du sulfate de calcium dihydraté appelé "gypse artificiel" ou "phospho-gypse" (Fontanille, 1973). Rejeté dans les eaux, ce produit va se solubiliser plus ou moins rapidement, mais finit par constituer un dépôt de sulfate sur les fonds et les berges nuisible au développement de la flore et de la faune aquatiques. Il s'agit là d'une atteinte sérieuse au milieu naturel, puisque chaque tonne de P_2O_5 obtenue nécessite trois tonnes de phosphates naturels et entraîne le rejet de quatre tonnes de sulfate de calcium, soit, pour la France, une production annuelle de gypse artificiel estimée à 3 millions de tonnes à moyen terme.

Parmi les solutions étudiées pour différentes usines d'acide phosphorique, il convient de citer une expérience de valorisation et récupération du gypse synthétique par fabrication de carreaux de plâtre. Cette expérience a été lancée dans la région Rhône-Alpes où l'expansion de l'industrie du bâtiment et le manque de gisement important de gypse naturel offrent un marché potentiel intéressant: une installation pilote de 120 t/j de capacité a ainsi montré que des éléments préfabriqués de plâtre artificiel peuvent être préparés dans des conditions économiques satisfaisantes. Restent encore à préciser certains aspects d'épuration et d'utilisation avant extrapolation à l'échelle industrielle et dans des contextes régionaux autres.

Dans le secteur sidérurgique, l'importance pondérale de certains déchets est également

caractéristique: selon les procédés d'affinage et de moulage, il faut par exemple compter de 300 à 900 kg de laitier par tonne de fonte, ce qui, pour l'ensemble de la France, donne une production annuelle de l'ordre de 14 millions de tonnes.

Que les laitiers soient obtenus par trempe dans l'eau ou par refroidissement lent, ils sont de moins en moins mis en crassier, puisque leur taux d'utilisation est passé de 60 à 86% entre 1960 et 1970 (Kunicki, 1972).

Le laitier granulé, de structure vitreuse, trouve un débouché remarquable dans la fabrication des ciments et la construction des assises de chaussées en raison de ses propriétés hydrauliques et pouzzolaniques particulières (4,8 millions de tonnes en 1970).

Le laitier concassé, de structure cristallisée, voit son domaine d'utilisation partagé entre les granulats pour bétons, les graves artificielles pour routes, les calibrés pour ballasts (plus de 5 millions de tonnes en 1970).

Les laitiers de haut fourneau connaissent d'autres emplois qui consomment des tonnages plus faibles que les précédents, mais risquent de se développer dans l'avenir: ils servent ainsi à fabriquer de la laine minérale, des verres, des matériaux vitro-cristallins.

Dans ces conditions, la valorisation des laitiers offre des avantages indéniables: à court terme, elle entraîne une incidence économique non négligeable sur le prix de revient de la fonte en supprimant d'abord le stockage et en procurant ensuite des revenus supplémentaires; à plus long terme, elle représente une nouvelle ressource en matériaux qui peuvent être substitués à certaines matières premières.

La récupération des cendres volantes des centrales thermiques mérite un intérêt comparable: sur 3,8 millions de tonnes produites en 1970 en France, 3,4 millions de tonnes ont été vendues, soit près de 90% entrant dans (Hanquez, 1973; Jarrige, 1971):

- — la préparation des liants hydrauliques et la fabrication de pâte à ciment (consommation en palier vers 1,3 million de tonnes depuis 1965);
- — les travaux routiers et remblais sélectionnés (forte progression de la demande, passant en dix ans de 12 000 tonnes à presque 2 millions de tonnes et obligeant à des reprises importantes en terrils);
- — la production de bétons cellulaires et d'agrégats frittés (marché d'environ 100 000 tonnes).

L'exploitation des propriétés des cendres volantes en remplacement des matériaux courants atteint maintenant un degré tel qu'il est question de prendre des dispositions particulières pour en garantir l'approvisionnement. Renversement complet de situation, ces rejets deviennent un produit rare et seront même réservés à des usages de plus en plus nobles.

Comme on le constatait déjà pour les industries extractives, la récupération de déchets spécifique au type d'industrie de transformation ne peut cependant être réalisée qu'après que soient acquises les caractéristiques particulières au matériau et que soit pris en compte l'ensemble des facteurs extérieurs de développement, facteurs géographiques, économiques, administratifs, humains.

Quant à la récupération de déchets spécifique au type de produit d'industrie de transformation, elle relève du domaine classique des industries et commerces de la récupération, regroupées en quatre divisions traditionnelles: les vieux papiers, les textiles, les ferrailles, les nonferreux, auxquelles depuis quelques temps une division des plastiques a été ajoutée. Le poids de cette activité dans l'économie nationale est notable puisque, employant 35 000 salariés, elle totalise un chiffre d'affaires de 10 milliards de francs et se classe au 6ème ou 7ème rang de l'industrie.

Obéissant à des impératifs commerciaux évidents, elle concerne surtout les déchets de fabrication, parfois de consommation, qui sont les plus facilement accessibles et valorisables. En 1972, elle a permis ainsi de recycler:

— 1,6 million de tonnes de vieux papiers dont peut-être 50 000 tonnes de chutes de fabrication, pour une consommation de 5,4 millions de tonnes;
— 8,4 millions de tonnes de ferrailles comprenant environ 2,5 millions de tonnes de chutes neuves, pour une consommation de 18,5 millions de tonnes d'acier;
— 105 000 tonnes de déchets d'aluminium avec une proportion en déchets neufs de l'ordre de 50% pour une consommation dépassant 5000 000 tonnes;
— environ 150 000 tonnes de déchets de cuivre sur une consommation de presque 500 000 tonnes.

Mais les taux de récupération de la plupart des déchets seraient augmentés fortement si la profession suivait les exemples évoqués précédemment à propos d'autres secteurs industriels. Dépassant le stade actuel d'exploitation des sources les plus immédiates de déchets, elle pourrait notamment développer son activité en mettant en valeur de nouveaux domaines d'approvisionnement, comme les ordures ménagères.

A l'actif d'un tel programme, il aurait été ainsi possible d'inscrire, pour l'année 1971,

— une économie directe de matières rapportant:
  . 500 millions de francs pour la totalité des ordures ménagères,
  . presque 400 millions de francs pour la fraction collectée,
  . plus de 200 millions de francs pour la fraction destinée à un procédé de traitement industriel;
— une économie indirecte d'énergie s'élevant à:
  . 14 milliards de kWh pour la totalité des ordures produites,
  . 11 milliards de kWh pour la fraction collectée,
  . 6 milliards de kWh pour la fraction traitée,

c'est-à-dire respectivement 9%, 7%, 4% de la consommation nationale de l'année considérée.

Mais au passif d'une opération de ce genre intervient l'importance des capitaux nécessaires tant aux recherches techniques qu'aux installations industrielles. Le marché de la récupération étant caractérisé par une instabilité des cours chronique, les investissements risquent d'y être difficiles. Des mesures de réglementation, de réorganisation seront donc indispensables à l'amélioration des conditions de développement dans ce domaine.

En conclusion de cette représentation de divers aspects de récupération des rejets solides en France, il est intéressant d'analyser ce qui fait l'originalité d'une telle entreprise dans ses motivations et son action.

La situation actuelle montre que l'utilisation des déchets a d'abord été motivée par des raisons commerciales: selon la valeur et la nature des matériaux, leur récupération est déterminée par les besoins d'un marché d'importance régionale, nationale ou même internationale qui subit l'influence du marché des matières premières, de la spéculation, de la concurrence. Mais depuis quelques années, la lutte contre les nuisances peut introduire de nouvelles possibilités d'échanges économiques en incitant à valoriser des produits jusqu'alors marginaux.

La remise en circulation des déchets récupérés dépend de leur qualité et s'effectue de deux manières distinctes. Pour les matériaux qui sont plus des co-produits d'industries d'extraction ou de transformation que des biens usés, il s'agit surtout d'une insertion dans un cycle d'élaboration simplifié analogue à celui d'une matière première. Pour les autres

déchets, il en va différemment: leur cycle d'utilisation se déroule en sens inverse puisque, partant d'une matière élaborée ou pré-élaborée, il la ramène à un stade de transformation où elle est purifiée, rénovée avant d'être à nouveau consommée. Mais, dans un cas comme dans l'autre, les industries de récupération se heurtent finalement aux tendances de consommation qui diversifient considérablement leurs activités et peuvent imposer à leurs produits un alignement qualitatif pas toujours justifié sur les produits fabriqués à partir des matières premières.

Et ce sont essentiellement ces faiblesses de planification de marché, d'organisation de structure, qui devront être surmontées pour que la récupération des déchets atteigne un niveau supérieur de développement et devienne le remède principal au gaspillage et à la pollution.

SUMMARY

An overview of the French resource recovery situation and trends is presented, with examples related to mining wastes, phosphogypsum, iron making slags, and post-consumer materials.

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STATUS OF MUNICIPAL REFUSE PROCESSING IN THE UNITED STATES

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I have been asked to describe to you what the United States is doing to treat municipal urban refuse and to recover the valuable constituents therein. During the past few years there has been a major effort made in the United States to overcome the mismanagement of solid wastes which has resulted in land, water, and air pollution as well as in the irrevocable loss of enormous quantities of metal, mineral, and energy resources. Throughout the country many organizations are trying to develop new, efficient, and effective solid-waste-disposal practices. There is also a search for a total systems approach to recover and recycle the values in these wastes to defray the rising costs of their disposal.

Equally as important as the concept of development of a total systems approach to solid-wastes problems is that of preventing environmental pollution. There is an understanding that wherever possible, each new industry, factory, or public utility must incorporate in its place of operation a sound system of solid-waste utilization and/or disposal.

Generation of solid wastes in the United States from all sources can be broadly classified into six major groups: urban, industrial, mineral, agricultural, automotive, and powerplant fly ash. Estimates of urban waste vary depending upon calculation methodology. The Bureau of Mines estimates that a total of 4.6 billion tons of wastes are generated each year; about 300 million tons come from domestic, municipal, and commercial sources; industrial operations produce another 110 million tons; 2.5 billion tons come from agricultural sources; mining operations yield 1.7 billion tons; and 30 million tons of fly ash accumulate as a result of power generation. In addition 9 million cars, buses, and trucks are junked annually in the United States, and probably over 15 million junk cars can be found in auto graveyards as well as wrecking and scrap-processing yards. Wastes generated throughout the country amount to over 120 pounds per capita per day. By 1980 we expect that this figure will increase to at least 150 pounds per capita per day.

We are only beginning to utilize these solid wastes. Throughout the United States, only about 160 million of the 300 million tons of municipal refuse is regularly collected by public agencies and private refuse firms. The remaining 140 million tons is still being abandoned, dumped at the point of origin, or hauled away by the producer to uncontrolled disposal sites. The collected wastes include among other things 55 million tons [illegible] paper and paper products, 12 million tons of iron and steel, 13 million tons of [illegible] million tons of aluminum, zinc, lead, tin, and copper. Many consi[illegible] be "urban ore" since it represents an ever-increasing resource of [illegible]

Such material, if recycled from post-consumer solid wastes, could provide 7% of the iron and steel, 18% of the aluminum, 20% of the tin, and 14% of the paper consumed annually in the United States. While these percentages represent the practical potential for resource recovery to provide new material supplies, actual recovery levels will be constrained by technical, economic, and institutional factors.

Over the years this urban ore has been primarily discarded in the United States in open dumps and landfills. By 1972 only about 30 million tons of refuse was being incinerated in over 200 municipal incinerators. Use of this method of discarding refuse has been slowly increasing as municipalities began to exhaust the land available for dumping purposes. On the average, a city of 10,000 generates enough refuse each year to fill 1 acre of ground 7 feet deep. When this refuse is incinerated the volume is decreased by 90%, and the weight is decreased by about 75%.

Burning refuse to generate steam in the United States dates back to 1889 when a refuse-burning steam generator was built in New York. During the past few years there have been at least twelve steam-generating incinerators operating in this country, utilizing the roughly 5000 Btu per pound of energy contained in the refuse material. However, units in Atlanta, Ga., and Miami, Fla., were recently closed because of air-pollution problems. Several new facilities are now being constructed. A list of the incinerators in the United States having major heat-recovery ability are presented in Table 1. The table does not list the basic incinerators where refuse is simply burned to reduce the volume of wastes being discarded.

TABLE 1. Incinerators with major heat-recovery features

Location	Type of installation	Design refuse capacity (tons/day)	Heating value of refuse (Btu/lb)
Atlanta, Ga.	Volund[b]	700	3900
Boston, Mass.	Water-wall[a]	1200	4500
Braintree, Mass.	Water-wall	240	5000
Chicago, Ill. (Southwest)	Refractory	1200	—
Chicago, Ill. (Northwest)	Water-wall	1600	5000
Harrisburgh, Pa.	Water-wall[a]	1600	—
Hempstead, N.Y. (Merrick)	Refractory	700	4300
Hempstead, N.Y. (Oceanside)	Refractory	600	4500
Miami, Fla.	Refractory[b]	900	—
Nashville, Tenn.	Water-wall[a]	1300	—
Norfolk, Va. (U.S. Naval Station)	Water-wall	360	4700
Oyster Bay, N.Y.	Refractory[a]	—	—
Philadelphia, Pa. (Harrowgate)	Refractory[a]	300	—
Providence, R.I.	Refractory[a]	—	—

[a] Under construction. [b] Closed temporarily.

With passage of the Solid Waste Disposal Act of 1965, the Federal Government became fully involved with municipal waste management, and initiated studies and demonstration funding of potential recovery processes and systems. Since that time there has been a kind of technological revolution underway in the United States, with many organizations attempting to develop methods for separating and recycling to the economy the useful materials in refuse. The U.S. Bureau of Mines was among the first government agencies to

initiate research activities and has developed two separate systems for processing incinerator residues and unburned refuse into their component products. The Environmental Protection Agency was eventually singled out as the avenue through which large-scale resource-recovery demonstration projects would be funded, and at present EPA is supporting six of these projects, each of which is coordinated with a State or local government. The six systems have different features, but all are designed to recover the mineral and metal values found in municipal refuse. Four of the systems have provisions either to utilize the combustible fraction as a direct source of heat or to convert it into oil, gas, or char which can be used as a supplement in existing oil, gas, or coal-burning facilities. Table 2 briefly describes each of these demonstration projects. Two of the demonstration plants have been completed and are in operation. The other four are either in the final planning stage or now under construction. The costs and sources of funds for these projects are given in Table 3.

TABLE 2. Federal resource recovery demonstration projects

Location	Process type	Resources recovered	Size (tons/day)
Lowell, Mass.	Incinerator residue separation	Ferrous metals, glass, aluminum, copper/zinc	250
Franklin, Ohio	Wet pulping for recovery	Paper fiber, ferrous metals, glass, aluminum	150
St. Louis, Mo.	Shredded waste as a fuel	Shredded combustible waste, ferrous metals	650
Wilmington, Del.	Shredding for fuel recovery and materials separation	Humus, humus as fuel, ferrous metals, aluminum, glass	500
San Diego, Calif.	Pyrolysis to produce fuel oil-steam	Oil, ferrous metals, glass, aluminum	200
Baltimore, Md.	Pyrolysis to produce gas-steam	Steam, ferrous metals, glassy aggregate	1000

TABLE 3. Funding arrangements for demonstration tests (approximate)

Test site	Private funds	State or municipal funds	Federal funds	Total project
Lowell, Mass.	$—	$800,000	$2,400,000	$3,200,000
Franklin, Ohio	350,000	650,000	2,100,000	3,100,000
St. Louis, Mo.	950,000	350,000	2,600,000	3,900,000
Wilmington, Del.	—	4.760,000	9,000,000	13,760,000
San Diego, Calif.	450,000	600,000	2,960,000	4,010,000
Baltimore, Md.	—	10,200,000	6,000,000	16,200,000

Lowell, Mass. The principal objective of this project is to demonstrate that the valuable components of incinerator residue can be economically recovered. The city of Lowell will build a full-size processing plant capable of handling 250 tons of incinerator residue in 18 hours. Raytheon Service Corp. has the responsibility to design and operate the plant for the first year; thereafter responsibility may transfer to the city of Lowell. R

Lowell and several neighboring communities will be processed in the facility. The technology employed in the demonstration plant will be based upon that developed by the Bureau of Mines in a pilot plant at College Park, Md. The process uses basic mineral beneficiation equipment. The residue is shredded to minus 1 inch size, passed over a magnet separator to remove ferrous metals, and wet-screened on 20-mesh sieves to remove the bulk of the sand and glass. The coarse is reground and subjected to another 20-mesh screening. The bulk of the nonferrous metals remain larger than 20-mesh while the glass, being more friable, is readily ground to smaller particles. The fines are sent to a flotation cell where the glass is removed from ceramic and other impurities. The aluminum is removed from the coarse nonferrous product by heavy-media separation. The Lowell plant will recover more than 40,000 tons of products—steel, nonferrous metals, and glass from incinerator residues annually. With the major increase in scrap metal prices early in 1974 the expected revenue is now over $1.1 million. The Bureau published an economic evaluation of the process based on its pilot plant experience and estimated the various products to be worth $22 per ton of incinerator residue processed. With operating costs of $4 per ton of input, the Bureau indicates a net gain of $18 per ton can be expected.

Franklin, Ohio. The project demonstrates a wet refuse-disposal and resource-recovery system capable of processing municipal refuse and producing metals, color-sorted glass, and paper fiber in a recyclable form. The Black-Clawson Co. designed and built the 150-ton-per-day plant for the city of Franklin. The basic feature of the disposal system consists of a hydrapulper, a wet grinder that pulps the incoming refuse. Odd bits of metal, tin, cans, and other nonpulpable and nonfriable materials are ejected from the hydrapulper through an opening in the side of the tub and sent to a magnetic separator to recover the ferrous metal portion. A liquid cyclone takes the pulped waste from the hydrapulper and extracts small heavy objects, mostly glass intermixed with some nonferrous metals, wood, and plastics. The remaining pulp passes from the liquid cyclone into a fiber recovery subsystem, where the pulp undergoes further cleaning and dewatering. The final product consists of low-grade, long-fiber paper pulp suitable for recycling. Rejected short-fiber paper pulp is piped to an incinerator for disposal. This incinerator is also being used to burn filtered sewage sludge from an adjacent sewage-treatment plant. The heavy materials from the liquid cyclone are processed in a separate subsystem employing magnetic separation, screening, air classification, and optical sorting to produce an aluminum-rich concentrate and color-sorted glass. Revenue from the products collected is estimated at $6.50 per ton of input refuse. Operating costs are estimated at $15.10 per ton for a net cost of $8.60 per ton of refuse treated.

St. Louis, Mo. In this project the combustible fraction of urban refuse is separated and utilized as a partial fuel supplement for the suspension burning of coal in a commercial power plant. Two facilities are involved in the test studies. The City of St. Louis operates a 650-ton-per-day municipal waste-processing facility, located adjacent to one of their municipal incinerators while the Union Electric Company operates the fuel-firing facility. In the separation facility incoming refuse is shredded 1½-inch particle size. The shredded waste is air classified into two fractions: a "light" combustible waste fraction containing about 80% of the incoming waste, and a "heavy" waste fraction containing metals, glass, rocks, rubber, and heavy plastics. Ferrous metals are separated from this latter fraction by magnetic separation. The light combustible waste fraction is trucked 18 miles to the Union

Electric Co. Meramec power plant where the fuel is pneumatically fed, at the rate of 10–15% of the boiler's fuel requirement, to an existing 125-megawatt suspension-fired boiler. The primary boiler fuel is coal. Operation experience has shown that approximately 2 tons of light refuse can replace 1 ton of coal in supplying heat to the boiler. Economic projections indicate a net cost to the City of St. Louis of $4 per ton of refuse processed after selling the ferrous fraction and the fuel supplement and sending the remainder to landfill. There is a savings of $3 per ton of fuel replaced expected by the Union Electric Co. The company is considering expanding its operation to permit burning of light combustibles in each of the four boilers at the Meramec power plant. This could involve the processing of 8000 tons of refuse daily. The current demonstration project has both national and international attention.

Wilmington, Del. Here it is planned to demonstrate that the combustible fraction in municipal refuse can be utilized as a supplement in oil-fired boilers, either directly or as a composted material. The State of Delaware has operational responsibility for this facility. This process is not completely designed at the present time. It is planned to treat 500 tons of municipal refuse, 15 tons of industrial waste, and 230 tons of 8% solid sewage sludge daily. Incoming municipal refuse will be shredded to a 6- to 8-inch particle size. The shredded waste will be air classified into two fractions: a "light" combustible waste fraction containing about 60–75% of the incoming waste, and a "heavy" waste fraction containing metals, glass, wood, plastics, textiles, rubber, and rocks. The light fraction will be shredded again to a 1- to 2-inch particle size. Most of the reshredded light fraction will then be sent directly to a power plant for use as supplemental fuel in oil-fired boilers. The remaining light fraction will be mixed in aerobic digesters with partially dewatered sewage sludge for use as supplemental power-plant fuel, or compost, or both, depending upon market conditions. The heavy fraction will be processed to remove ferrous metals, and the remaining heavies (nonferrous metals, glass, wood, leather, plastics) will be mixed with selected industrial wastes (wood, cardboard, plastics) and pyrolyzed. Heat from the pyrolysis gases will be used to help dewater the sewage sludge. Aluminum and glass will be recovered from the pyrolysis residue. The remaining residue goes to landfill. It is anticipated that the products from this system will be valued at $7 per ton of raw solid waste treated. The net cost of the process will be slightly over $15 per ton of waste processed.

San Diego, Calif. This study is to be undertaken to determine how the light combustion fraction of municipal solid waste can be flash pyrolyzed to an oil product and used as a supplementary fuel in an existing power-plant boiler. The test program is still in the design stage, and construction of the 200-ton-per-day plant has not begun as yet. The County of San Diego will have operational responsibility for the system. The key feature will be a flash pyrolysis unit developed by the Garrett Research and Development Co. Based on pilot plant studies, slightly more than 1 barrel of low-sulfur oil can be obtained from each ton of raw municipal refuse. The plan is to first shred the refuse to 3-inch particle size and then separate it mechanically into light and heavy fractions. The light material will be dried and shredded further to a fine particle size prior to flash pyrolysis at a temperature of about 900°F. An oil-like liquid with a heat value about 75% that of No. 6 fuel oil can be condensed from the pyrolysis gases. The oil-like liquid will be used as supplementary fuel in an existing San Diego Gas and Electric Co. boiler. The heavy waste fraction will be processed further to separate ferrous metals by an electromagnet, aluminum by a new process,

and glass by froth flotation. Initial estimates indicate the net value of the products from the system to be around $4 per ton of refuse, net cost of the process to be almost $6 per ton of refuse.

Baltimore, Md. This project is designed to demonstrate that refuse can be converted into a gas which in turn can be utilized as a fuel supplement in the generation of steam. The city of Baltimore will own and operate a pyrolysis plant developed by Monsanto Enviro-Chem Systems, Inc. Monsanto has designed and is now constructing the system, known as the LANDGARD process, under a turn-key contract with money-back performance guarantee provisions concerning plant operation, the ability of the plant to meet both local and Federal air-quality standards, and the putrescible content of the residue (must be less than 0.2%). Monsanto's maximum pay-back liability is $4 million, or about 25% of the contract price. Construction of the plant is now underway and is expected to be complete by the end of 1974. The plant is designed to handle mixed municipal refuse including tires and white goods. All incoming waste is to be shredded to a 4-inch particle size and then conveyed to a rotary pyrolysis kiln. About 7 gallons of No. 2 fuel oil per incoming ton of waste will be burned to provide heat for the pyrolysis reaction. In addition, about 40% of stoichiometric air will be added to the reactor to allow some of the pyrolysis gases to burn and add additional heat to the unit. The pyrolysis gases leave the kiln and then are combusted in an afterburner. The hot afterburner exhaust gases pass through waste-heat boilers that generate 200,000 lb of steam per hour for sale to the Baltimore Gas and Electric Co. The steam will be used eventually for heating buildings in downtown Baltimore. The pyrolysis residue will be water quenched and passed over magnetics to remove the ferrous metals. Water flotation and screening processes will separate a glassy aggregate fraction which is planned for use as an aggregate with asphalt for street construction. The final char residue goes to landfill. It is estimated that about $4.50 per ton of input waste will be obtained from the sale of steam, ferrous, and glassy fractions. Net cost of the project is estimated at slightly over $6 per ton of refuse processed.

Other systems. There are several other systems under investigation at the present time for which demonstration projects have not been committed or contracted for.

U.S. Bureau of Mines. The Bureau has been operating a pilot plant capable of treating 5 tons of unburned municipal refuse per hour at its College Park, Md., research center. The process under investigation involves first flail-shredding the refuse to something less than 8 inches in size in a flailing mill, passing the shredded material past a belt magnet to remove the ferrous metal, then passing the nonmagnetic material through a horizontal air classifier. In this apparatus the nonmagnetics are divided into a heavy nonferrous fraction, a light combustible fraction, and a mixed middling fraction. The middling fraction is fed into a rotating trommel screen with ¾-inch holes. The bulk of the glass and putrescibles fall through the screen and are separated in a mineral jig. The oversize materials, primarily nonferrous metals, heavy paper, cardboard, and large pieces of glass, pass through to a secondary shredder where they are reduced to less than 1 inch in size before dropping into a second air classifier of the zig-zag variety. Here the remainder of the light combustibles are removed from the mixed glass and metal heavies. The latter can be separated by electrostatic separation. Further development is under way to improve product recoveries and separation of the nonferrous metals. The initial flail-type shredder makes the tin cans especially suitable for detinning since the cans are not compacted excessively, but average

10 lb/ft^3 in density. The overall process is expected to be ready for demonstration testing by mid-1975.

Combustion Power Co. This company has been developing a system for converting municipal refuse into gases which will directly drive a turbine connected to an electrical generator. Known as the CPU-400 project, the system is still in its pilot plant phase. After burning, the refuse is sent to a landfill. Before entering the turbine the exhaust gases from the burning zone must be thoroughly cleaned to a degree at least 10 times that which is allowed by Federal regulations for exhausts from municipal solid-waste incinerators. This degree of cleanliness is necessary in order to reduce the likelihood of eroding or corroding the surface of the turbine blades. The extreme degree of exhaust gas cleanliness required has proven to be one of the major technical hurdles over the past several years. Still another problem lies in the buildup of deposits on the turbine blades in spite of a high degree of gas cleaning. The process is not being tested outside of Combustion Power's facility in Menlo Park, Calif.

National Center for Resource Recovery. This organization is developing what they cal- an "Equipment Test and Evaluation Program" in conjunction with the District of Columl bia's Department of Environmental Services at the District's refuse incinerator facility. The program is intended to produce performance data on resource-recovery equipment and unit operations, including air classifiers, and rising current and magnetic separators. Also it is planned to develop data on the preparation of a refuse-derived fuel. Aside from this test and evaluation program NCRR has contracted with the City of New Orleans to furnish advice and technology for the construction of a prototype municipal solid-waste processing facility, capable of treating 650 tons per day of residential refuse. It is planned to shred the refuse and air classify it into light and heavy fractions, with the light fraction to be used as a sanitary landfill or as a fuel source. The heavy fraction will be magnetically separated to recover ferrous metals. Small pieces of mixed glass will be screened out. High-density, heavy-media will be utilized to separate the large pieces of glass and aluminum from the other nonferrous metals. The mixed glass and aluminum will be separated electrostatically, and the glass fraction will be optically color-sorted. Construction of the prototype plant had not begun by mid-1974.

Union Carbide Corp. The Linde Division of Union Carbide Corp. of New York is presently constructing a 200-ton-per-day module of their Purox solid-waste pyrolysis system in Charleston, West Va. The plant is intended to be operated in 1974. In the Purox process, refuse is fed into an air-locked feed hopper without prior shredding or other pre-processing. Then it is slowly fed into a vertical shaft pyrolysis unit. Oxygen is fed into the unit beneath the pyrolyzing refuse to provide gas for combustion. The use of pure oxygen as compared to air reduces the air-handling volumes and subsequently reduces the size of the air-pollution-control equipment required. According to Union Carbide's laboratory data, the volume of the refuse will be reduced by 95–98%, and a combustible off-gas will be produced. This off-gas has a heat value of 300 Btu per scf, compared with 1000 Btu per scf for natural gas. Over 80% of the fuel value of the original refuse (valued at 5000 Btu per pound) is expected to be recovered in the off-gas generated in this process.

Combustion Equipment Assoc., Inc. This firm, in conjunction with the North American Incinerator Corp. of Boston, Mass., has designed and is now constructing a 600-ton-per-day

municipal refuse processing plant for treating solid waste from Brockton, Mass., and other nearby communities. The refuse is to be shredded and air classified, and the ferrous fraction magnetically separated. The light fraction will be reshredded and further processed to produce a combustible "Echo-Fuel" which has a heat value of 6900 Btu/lb. The company plans to transport this fraction to markets within a radius of approximately 75 miles where the fuel will be converted into steam. The residue from the separation process, primarily nonferrous metals, glass and dirt, is to be sent to a nearby landfill. Combustion Equipment Assoc., Inc., has recently been awarded a contract by the State of Connecticut to construct a resource recovery facility in the City of Berlin. The size of this plant is intended to be 1500 tons per day.

Garrett Research and Development Corp. Aside from its EPA demonstration project in San Diego, Calif., this firm was awarded a contract by the State of Connecticut in May 1974 to build a 1200-ton-per-day municipal solid-waste-processing plant in Bridgeport, Conn. The plant will employ the basic Garrett technology.

By midyear 1974, there were over a dozen additional facilities planned for an equal number of cities throughout the United States. None of these facilities has progressed sufficiently to warrant individual description. With such activities taking place in this country, there is little doubt that the era of discarding our municipal solid waste is rapidly passing, and the time when these wastes will be utilized as useful urban ore is drawing nearer. There is little doubt that this trend also will soon be evident in Europe since several experimental processes are now being investigated in Spain, France, England, and The Netherlands.

UTILIZATION OF SOLID WASTE IN SPAIN

JORGE SÁNCHEZ ALMARAZ

INTRODUCTION

The problems of utilization of solid-waste material has been taken up seriously in Spain in both research and industrial aspects. The following projects illustrate this assertion:

Research on Solid Waste Recycling is sponsored by E. N. Adaro through their Research Center in Madrid, where they have installed a pilot plant for the treatment of urban raw refuse.

Solid Waste Management Plans to obtain information and data regarding the generation of urban and industrial wastes are being conducted by different official organisms and private firms.

An Incinerator Plant for electric energy recovery is under construction in the city of Barcelona.

INSTALLATION AND RESULTS OF THE FIRST SPANISH PILOT PLANT FOR THE TREATMENT OF RAW REFUSE FROM MADRID WITH USBM TECHNOLOGY

A little more than a year ago, under the Plan for Scientific and Technical Cooperation between Spain and the United States, through the National Science Foundation and the Instituto Nacional de Industria, a cooperative agreement providing for mutual scientific and technical aid based on research programmes for solid-waste treatment was started between the United States Bureau of Mines and the Empresa Nacional Adaro de Investigaciones Mineras, S.A.

As a result of such an agreement Adaro's raw refuse treatment pilot plant, constructed in Madrid, was inspired by the USBM flow-sheet utilized in their Metallurgy Research Center at College Park, Maryland.

It must be noted that the plant was commissioned last October using synthetic refuse previously prepared for testing each of the machines integrated in the flow-sheet.

The synthetic refuse was composed of paper, cardboards, plastics, wood, rubber, leather, tin cans, scrap iron, metals, glass bottles and other materials, aside from decayable organics.

It was not until last February that the plant began to treat real raw refuse from Madrid. For this reason the information and data to be presented is rather scarce and should certainly be considered as preliminary.

On the other hand, sufficient statistical information on the composition of raw refuse

generated in Madrid is available. These had already been gathered by the Town Hall Waste-collecting Department after a systematic sampling campaign conducted through the different classified areas of the City and along a complete 4-season yearly cycle.

In this respect, it is important to note the very marked differences between the composition of the refuse generated in this City and that produced in highly developed countries like the United States, Canada, Sweden, and others. The enormous quantities of food organics, which may amount to as much as 60% of the total refuse (Fig. 1), is responsible for the main difference from what we are used to seeing in the above-mentioned countries. The high moisture content is also due to the same reason.

Waste composition	Per cent range wet basis	Type	Per cent range
Metals	2.5–6	Non-combustible	7–26
Glass	2.5–10		
Ash, other inerts	2–6		
Organics	30–60	Putrescible	30–60
Papers and cardboards	15–30	Combustible	19.3–51
Plastics	3–12		
Fabrics	1.2–3		
Wood	0.1–4		
Rubber	0.1–1		
Leather	0.1–1		

Moisture range 30–50% Specific weight range 0.1–0.2 t/m^3

Fig. 1. Typical urban refuse composition in Madrid.

Description of the plant

The pilot plant flow-sheet is illustrated in Fig. 2. The main difference between this flow-sheet and that of the USBM is shown in thick lines, this part of the circuit is actually being tested for its efficiency.

Lorries coming from Madrid discharge the refuse on outdoor platforms and, from this point, the refuse is fed on to a belt conveyor which, in turn, feeds the plant located indoors.

The primary shredder, which is provided with two 40-h.p. twin motors, is already inside the building.

The first separating step takes place in the light air classifier. The papers and plastics separated at this stage are collected in Cyclone no. 1.

A heavy-duty overband magnetic separator follows next in the process. The magnetic fraction obtained is particularly clean in this case as a result of the lifting effect produced on the flowing material in the previous stage.

The primary air classifier comes in to make a three-product separation: heavy, light, and intermediate products.

The trommel, which follows next, is provided with 60-mm round holes

The undersize of the trommel screen plus the "heavies" from the primary air classifier are further classified on a vibrating screen. This operation provides for a preliminary glass-enriching step.

The oversize coming from the trommel screen is conveyed to the secondary shredder.

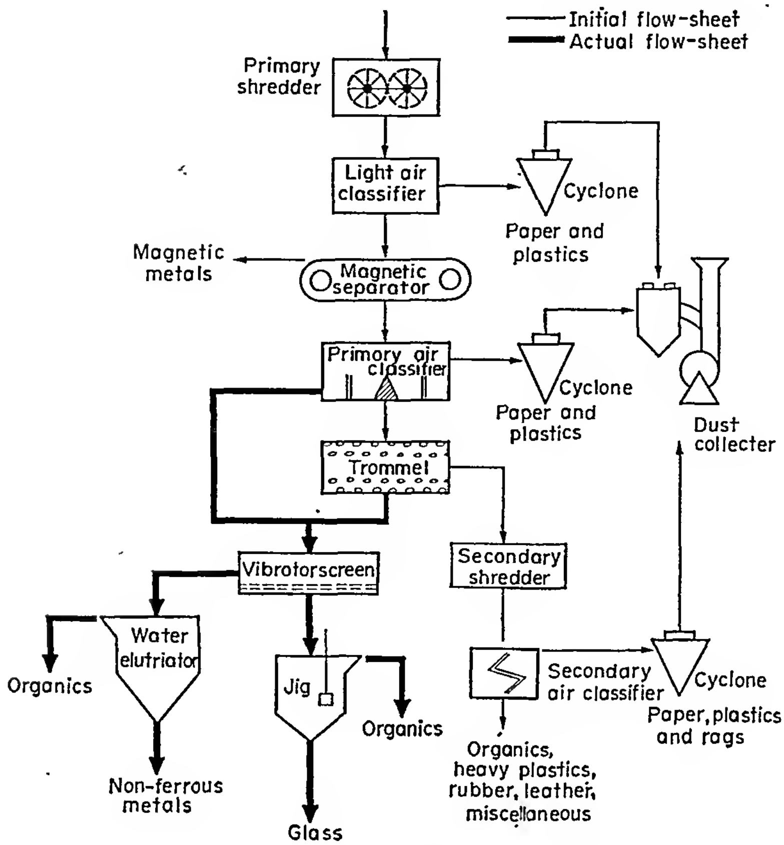

Fig. 2. Pilot plant flow-sheet.

At this stage the oversize is sheared down to sizes smaller than 25 mm by means of knife-edge cutters actuated by a 75-h.p. motor.

The material, thus reduced in size, is subjected to a final counter-current pneumatic separation in the secondary air classifier.

The light products separated in both primary and secondary air classifiers are collected in separate cyclones nos. 2 and 3, respectively.

The necessary vacuum for the pneumatic classifiers is provided for by a 75-h.p. dust collector installed outside the building.

Operating results

The first results obtained in this plant, treating the raw refuse formerly illustrated, are summarized in Fig. 3. Again, the influence of a high proportion of food organics is noted by the fact that the "heavies" of the primary air classifier are mainly composed of such material; and because the high amount (50%) of undersize produced by the trommel screen is also integrated mainly by food organics.

The products collected in the three cyclones are described in Fig. 4 with regard to the paper fraction.

The composition of the heavy products obtained in the secondary air classifier is illustrated in Fig. 5.

	Composition	% feed	Temperature 70°C drying time (hours)	% moisture
Light air classifier Cyclone-1	Paper, plastics	10	24	40
Magnetic separator	Tin cans, massif iron, other metals	4		
Primary air classifier—heavy	Organics, glass	10	72	<15–34 mm >15–58 mm
Cyclone-2	Paper, plastics	1	24	20
Trommel	Organics, glass	50	72	>25–58 mm 25> × >15–57 mm <15–47 mm
Secondary air classifier—heavy	Organics, miscellaneous	2	72	10
Cyclone-3	Light metals, plastics, fabric	5	24	20
Overflow	Organics, ash, glass	5		
Loses		13		
	Total	100		

Fig. 3. Distribution of pilot plant products.

	Light fraction		Paper	
Products	Weight (kg)	Weight (%)	Contents (%)	Distribution (%)
Cyclone no. 1	81.20	61.9	79.54	79.4
Cyclone no. 2	7.30	5.5	83.58	7.3
Cyclone no. 3	42.75	32.6	25.51	13.3
	131.25	100.0	62.09	100.0

Fig. 4. Distribution of the light fraction and paper content.

Metals	13%
Plastics	74%
Wood	3.5%
Textiles	3%
Organic (bread)	6.5%
Total	100.0%

Fig. 5. Heavy products distribution of secondary air classifier.

Marketing of recycled products

We have been surprised to learn that there is a potential market for the products obtained in the cyclones with no additional treatment. Nevertheless, we believe in the possibility of obtaining better economic results with further processing of these products.

The prices for recycled metals (quoted in Spanish and American currency) are given in Fig. 6.

The prices of miscellaneous products from recycling operations are shown in Fig. 7.

Metals	Pts/t	$/t
Aluminium	20,000	330
Tin cans	2,000	33
Zinc	25,000	416
Copper	105,000	1750
Massif iron	5,000	83
Lead	21,000	350

Fig. 6. Price of waste metals for recycling (Spain, February 1974).

Paper	Pts/t	$/t
Clean paper	6,500	108
Other paper	3,500	58
Cardboard	4,500	75

Plastics	Pts/t	$/t
Colourless	23,000	383
Coloured	10,000	166

Fabrics		
Textiles in general	4,000	66
White textiles (cotton or wool)	15,000	250

Glass		
Shredded and mixed colours	1,250	20

Fig. 7. Price of waste materials for recycling (Spain, February 1974).

SOLID WASTE MANAGEMENT

Included in our solid-waste research programme is the solid-waste management for the "Costa del Sol" in southern Spain. The growing number of people visiting this part of Spain, particularly during the summer season, requires urgent control of solid-waste disposal. For this reason we have started statistical measurements of the amount and characteristics of the generated refuse in that area.

Figure 8 shows the variation of population in the city of Málaga during the winter and summer season, as well as the production of solid waste per capita in both seasons. It is interesting to note the lower production of waste per capita in summer. This is due to the fact that less waste is generated when people crowd in small communities like hotels and apartments.

Málaga City

400,000 hab. in the winter season
550,000 hab. in the summer season

URBAN SOLID WASTES GENERATED IN 1973: 116,000 tons

⟶ 317 t/day
⟶ winter season 0.76 kg/cap/day
summer season 0.64 kg/cap/day

Fig. 8. Urban refuse studies in the "Costa del Sol", south of Spain.

The solid-waste distribution by areas in the city of Málaga is shown in Fig. 9.

Finally, Fig. 10 shows that the average composition of solid waste generated in Málaga is very similar to that produced in Madrid.

Type	% Solid wastes generated
Urban area	60.2
Residential area	10.0
Touristic area	12.4
Commercial area	10.3
Market area	7.1
Total	100.0%

Fig. 9. Generated solid wastes distribution in different areas in Málaga City.

Metals	3.48%
Glass	6.52
Ash and other inerts	2.43
Organics	47.92
Paper and cardboard	21.24
Plastics	7.49
Miscellaneous (wood, rubber, leather, fabrics)	10.92
Total	100.00%

Fig. 10. Estimated composition of urban refuse generated by the City of Málaga during 1973.

INCINERATING URBAN REFUSE

The incinerator plant being constructed in Barcelona will be provided with three combustion units, with a total incinerating capacity of 1050 t/day.

This plant is expected to produce 18 MW/h and will be commissioned March 1975. Obviously, there is no practical data on this plant for the moment.

STATUS OF UTILIZATION OF SEPARATING WASTE PRODUCTS IN JAPAN

Keizo Kamiyama

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Thank you for extending me this opportunity to discuss with you the subjeet of the present status of the utilization of separating waste products in Japan.

PRESENT STATUS OF WASTE PRODUCTS IN JAPAN

Since the 1960s Japan has made tremendous progress in raising the gross national produetion by emphasizing the policy on economic growth, but accompanied with it there has also been the rapid increase in waste materials. Using the index of 100 in 1957 for both the actual gross production of Tokyo and the aecumulation of waste materials that were eolleeted by the metropolitan government, we notieed hardly any difference in 1960; however, both the GNP and wastes inereased sharply after 1960 and by 1972 they increased to 450. For example, the entire country of Japan in 1971 discharged approximately 800 million tons of industrial wastes.

This enormous amount of waste materials created a serious impact on the environment and eaused environmental disruptions throughout Japan.

The world today is familiar with the "Minamata disease" caused by the mercury discharged from a faetory, the "itai-itai disease" caused by eadmium, and the "kanemi oil symptom" caused by the PCB leaking into the cooking oil sold in the market.

The wastes from industries produeing petroehemical, paper and pulp, foodstuffs, and livestock have been the principal causes of offensive odor and water pollution.

On the other hand, the oil crisis and the inflation at the elose of 1973 direeted our attention to the importance of the researeh and development of waste materials.

STATUS OF RECLAMATION

The rate of reelamation of these wastes at this time is depressingly low.

For example, aluminum cans for beer and juice are produced at the annual rate of 15 million tons or the equivalent of 600 million cans, but the rate of recovery is praetieally zero. 5.7 million tons of plasties are produced yearly, but only 160,000 tons are utilized again for railroad eross ties and fences.

Nearly the entire production of 500,000 tons of tires has been reeovered for reuse.

Every year, there are about 2.8 million cars dumped away, but a meager 40% of it has been recovered.

Concerning electrical household appliances, the deplorable rate of 10% has been salvaged for scrap iron from the production of 1.88 million refrigerators and 1.3 million color television sets.

As you can readily notice from these examples, the rate of recovery is discouraging, and the recoverable wastes are burned or dumped at reclamation sites.

There are reasons for these disposal methods.

1. The recoverable waste is disposed unseparated from the total waste.
2. There is the lack of essential information about the disposer of wastes and the operating conditions of the scavengers or the amount of the disposed wastes.
3. The recovery system is imperfect, and the market for reproduced goods is inactive.
4. The situation is so uncontrolled that the disposal job can be easily and cheaply consigned to unlicensed agents.

SEPARATE COLLECTION OF WASTES

At present, autonomous corporations separate their collection of wastes not to reprocess wastes but mainly for the following reasons.

1. Prevent secondary pollution from the waste incineration plant.

Wastes containing a large portion of plastics, rubber and leather generate poisonous gas during incineration and leave a residue of heavy metal. The extremely high temperature during the incineration generates NOx from the raw garbage and further damages the furnace. The rate of 10.2% mixture of plastics in the wastes for Tokyo in 1970 is equivalent to almost 3 times that of a city in Europe. This indicates the seriousness of this problem.

2. Burn the greatest possible amount of ordinary waste.

The wastes collected and disposed of per day in Tokyo amount to 13,300 tons, but the incineration plants can only burn approximately 4000 tons. To alleviate this problem, the incombustible wastes and those that are inappropriate for incineration are separated at the waste collection point to gain maximum effectiveness in the burning of ordinary wastes.

3. Dispose wastes in accordance with the quality of the wastes.
4. Accelerate the recycling of resources.

The annual discharge of industrial wastes in Tokyo are as follows:

Construction wastes	1.87 million tons
Metallic wastes	1.26 ,, ,,
Sludge	.99 ,, ,,
Exhausted acid and alkali	9.92 ,, ,,

Hardly any of these wastes has been recycled.

The most urgent problem we encounter today is the scarcity of property for final processing, and it is becoming more and more difficult to secure the land.

Let us compare the number of damaged cars per 1 km^2 of inhabitable area for a country.

Japan	15.3 cars per km^2
U.S.A.	1.15 ,, ,, ,,
Great Britain	4.5 ,, ,, ,,
West Germany	6.8 ,, ,, ,,
France	2.3 ,, ,, ,,

We can easily notice from this comparison that Japan faces a serious problem of securing lands for processing.

Reproduction helps prevent pollution.

As you know, paper made from waste paper rather than pulp reduces pollution in the air by 26% and water by 65%, thus saving 70% of the energy. In a similar way, iron made from scrap rather than iron ore reduces air pollution by 14% and water contamination by 24%, a saving of 24% in energy.

For these aforementioned reasons, the problem of closed system recycling has grown extremely critical in Japan.

THE STUDY OF THE CLOSED SYSTEM

The following studies are being conducted in government institutes and laboratories:

1. The study of non-pollution organic synthesizing process: the sulfonation of aromatic group is carried in the organic solvents of sulfuric acid so that it will not yield any exhausted acid.
2. The study of non-pollution plating technique: instead of the conventional electroplating, the vacuum physical plating (ionized static plating) is employed.
3. The study of the utilization of pulp drainage: pulp drainage is used for irrigation after processing with active carbon (adsorption).
4. The study of the utilization and recovery of heavy metals in drainage.
5. The study of the utilization of industrial drainage: the sewage water and the secondary drainage from the integrated drainage processing facility of the chemical complex are processed with ozon to be recycled as potable water and water for industrial use.
6. The study of the utilization of wastes from the iron industries: the manufacture of artificial lightweight aggregate and combined lightweight castable from sludges and slags.
7. The study of the utilization of polymer wastes: the pulverization and thermal decomposition of plastics and old tires.
8. The study of the utilization of indirect desulfurized asphalt: the indirect desulfurized residual oil of crude petroleum is utilized as material for construction, adsorption agent, and fuel.

These are not, however, the closed-system studies based on careful consideration of influences on the natural system.

AIMING AT THE RECYCLE SYSTEM

In order to adopt the recycling, closed system to preserve the environment and conserve resources, I think that it is necessary to take the following measures.

We must consider two levels. One is the industrial level of production process, plant and industrial complex; and the other is the local level of the distribution of products to the general consumers. In considering the closed system of the industrial level, we must scrutinize closely the flow chart of the production process and be strict with the control of wastes.

It is only until we are unable to proceed any further with the flow chart under present standard of technical ability that we should permit the existence of the waste material.

Naturally, the material that was ejected from the system as waste should be placed in

an area for safekeeping far away from the environment. It should be preserved with an airtight seal at the final processing area.

The business enterprise that manufactures products for distribution to the consumers should establish a process that starts at the point of retrieving the product that eventually depreciated into a waste material, separating and decomposing it, and returning it as a raw material.

For example, in the process of production, there are robots working in an assembly line. When this product becomes a waste material, it should be disassembled and returned to production as a raw material by the robots working to reclaim waste materials. We must think about establishing this kind of system.

However, it is necessary that the material, decomposed to allow it to be restored to its original state, be put through a thoroughgoing anti-corrosion process.

In utilizing the industrial waste as an unused resource, a single plant or a single business enterprise cannot expect to be sufficiently effective. It must be consolidated!

The publication of the results of the researches and developments on the recycling of industrial wastes and the systematization of a consolidated development must be promoted positively by the government or the autonomous corporation.

On the problem of processing wastewater, the responsibility must be placed on the factories to recycle the drained water. The inspection of the drainage must be automated and must be checked constantly.

Among the SOx, NOx, COx, and hydrocarbon exhausted in the atmosphere, the SOx alone has been fixed, but the NOx, COx, and hydrocarbon should also be fixed.

Also, we should study the physical, chemical, and biological disposing methods that will convert all production processes to a production structure that will not upset the ecosystem.

DISCUSSION

VAN WAMBEKE: M. Gony nous a donné un excellent panorama des activités en France en matière de recyclage. Je voudrais quand même ajouter quelque chose pour les autres pays de la communauté européenne. Je passerai tout d'abord en Italie où il existe à Rome un procédé de triage automatique des ordures ménagères déjà fonctionnel et apparemment rentable. Il permet la récupération de différents produits: les métaux, le papier, et aussi les résidus organiques—principalement les végétaux—avec lesquels on fabrique de la nourriture pour le bétail. En Allemagne fédérale, la ville de Stuttgart est alimentée par du gaz généré par traitement des ordures ménagères. En Grande-Bretagne, les résidus d'huiles usées déversés dans l'environnement atteignaient plusieurs millions de tonnes par an: actuellement une société s'occupe du retraitement de ces huiles usées pour la fabrication d'une essence de qualité supérieure. Il y a deux gros problèmes à l'échelle communautaire, et je crois même à l'échelle de tous les pays, c'est l'organisation de la collecte des déchets—que ce soit des ordures ménagères ou des déchets industriels ou autres—et une législation qui favorise la récupération des déchets et qui garantisse aussi pour l'industrie qui traite ces déchets des débouchés.

MOSER: Permettez-moi Messieurs de vous citer un petit cas qu'on ne devrait pas oublier dans toutes les questions de recyclage. Par exemple, Mr. Kamiyama vient de citer l'exemple du papier en disant que le recyclage du papier apporte une réduction de la pollution, c'est-à-dire une réduction des charges imposées à l'environnement. Dans tous les secteurs du recyclage je ne crois pas que l'on puisse dire que c'est la solution pour une matière ou pas, mais on devra voir de très près chaque détail. Pour la question du papier, il y a aujourd'hui un grand problème qui est discuté et les gens ne sont pas encore d'accord. Est-il plus avantageux pour l'environnement d'incinérer le papier ou bien de le recycler? Car nous devons nous tourner vers l'avenir. Aujourd'hui il y a de grandes installations d'incinération où l'on produit de la chaleur, c'est-à-dire de l'énergie. Cette énergie est de nouveau utilisée pour chauffer de grands centres d'habitations; et en chauffant ces grands centres d'habitations par la chaleur produite par l'incinération, nous avons une grande diminution du SO_2 par le chauffrage ordinaire, ce qui représente une grande diminution des charges imposées à l'environnement. D'un autre côté, si nous recyclons du papier, nous avons une économie d'énergie au niveau de la fabrication et au niveau des ressources naturelles. Le point qui serait très important pour l'avenir c'est une quantification écologique de tous les problèmes, pas seulement jusqu'au premier stade mais plus loin. Aujourd'hui même où nous avons des usines d'incinération qui n'ont pas seulement une installation pour la production de la chaleur, mais où l'on a mis aussi une installation pour regagner les scories qu'on peut de nouveau utiliser à la construction des routes. Alors on peut dire qu'on a là un recyclage presque complet.

BROWN: Thank you. That's an important point.

BOL ALIMA: Je crois que je vais devoir introduire une petite fausse note dans cette discussion. Cette fausse note va surtout être due au fait peut-être que je vais appeler l'attention des membres de ce colloque sur des aspects du problème qui ne paraissent pas être leur préoccupation essentielle et cela se comprend. Je vais donc m'excuser si jamais j'étais quelque peu hors texte. En fait, nous avons parlé recyclage dès le début. Il faudrait peut-être que cette conférence qui se propose d'élaborer un plan d'actions pour l'humanité soit quelque peu claire sur les buts de ce recyclage, car ce plan d'actions ne pourra pas être totalement technique et dépourvu d'autres contraintes et d'autres paramètres. Car s'il s'agit d'un plan d'actions pour l'humanité, je dis bien pour toute l'humanité, il devrait requérir l'adhésion de cette humanité. Le problème du recyclage: "on recycle ou non?": je n'ai pas entendu de réponse sur ce point; j'ai entendu depuis hier des solutions qui sont proposées, des solutions parfois contradictoires et nous venons d'en avoir la preuve car en fait, qu'il s'agisse d'incinération ou de récupération par d'autres voies, les possibilités proposées par les experts varient. Il faudrait donc être d'accord au départ sur les buts de ce recyclage. S'agit-il de recycler—comme cela a été dit dans certains documents—parce que le monde est en face d'une pénurie de matières premières, et là le problème est un peu faussé, je crois, car certains experts éminents ont pu dire qu'il n'y avait pas lieu de parler de pénurie de matières premières, dans un avenir proche au moins, et en tout cas cela ne peut pas être le problème qui pourra requérir l'adhésion de toute l'humanité car à cette heure encore l'exploitation des matières premières et des ressources minérales constitue la base des économies de plusieurs pays. S'agit-il de recycler pour pouvoir accroître l'indépendance des pays déjà riches et industrialisés vis-à-vis de ces pays fournisseurs de matières premières et qui pour la plupart, au moins sur le plan technologique, sont des pays arriérés, et je crois que vous conviendrez avec moi que dans cette situation, ce plan d'actions pour l'humanité qui est en train de s'élaborer ne va pas requérir l'adhésion de toute l'humanité et qu'il sera un plan d'actions pour une certaine fraction de l'humanité. Je crains de constater par la liste des membres invités à cette conférence mondiale et le type des solutions proposées que ce soit les problèmes des Pays Développés qui restent la préoccupation majeure de nos réunions. S'agit-il enfin de recycler pour pouvoir assurer à l'homme, à l'humanité tout entière, un environnement convenable, un environnement qui lu permette de mieux se réaliser, objectif noble qui sans doute peut requérir l'adhésion de toute l'humanité. Le problème ne peut donc pas être résolu de façon partielle, c'est-à-dire en isolant le recyclage de son contexte et en semblant le réduire à un simple problème technique.

Les solutions doivent être globales, c'est-à-dire intégrer différents paramètres et considérer le problème

de la répartition des richesses et du travail dans le monde: répartition du travail et des ressources. Car, pour paraphraser le Professeur KEILING, certains pays qui n'ont encore que des "économies de misère" et qui sont en droit de penser qu'ils n'ont pas encore contribué à la pollution actuelle de l'environnement ne devront pas faire de façon non sélective les frais de la lutte contre la pollution. Monsieur le Président, je suis conscient, je l'ai dit, que ce sont des réflexions qui peuvent être hors texte et qui peuvent faire fausse note, car toute le monde a parlé ici des solutions techniques pour le recyclage alors que je considère la phase technique comme une simple étape finale. Revenons sur l'intervention du Professeur KEILING qui a invité le colloque à tenir compte d'une leçon qu'il considère comme historique: l'économie de misère qui s'est instituée en Europe après la guerre—je ne l'ai pas connue mais je n'ai que des raisons de croire à ce qu'il dit; doit-on se résigner à que celes problèmes de la pollution ne peuvent se résoudre qu'à travers des crises—ces crises pouvant revêtir l'aspect des holocaustes que l'on sait? Je suis enclin à ne pas être d'accord avec le Professeur Keiling sur le point que la pollution ait été supprimée par la guerre, cela pourrait d'ailleurs être dangereux et mettre en cause la capacité de l'homme à défendre l'espèce humaine de la disparition; je crois plutôt qu'il y a eu d'autres formes de pollutions: les bombes, les prisons, la faim, tout cela c'est de la pollution. Et je vais plus loin: la pollution psychologique—aspect qui n'a pas été évoqué jusqu'ici—qui peut être beaucoup plus grave car elle affecte la personnalité profonde de l'homme.

Ainsi donc, les problèmes de pollution ne peuvent être résolus qu'au moment des crises, ce qui donne totalement raison au Professeur Keiling puisqu'en fait on a l'impression que c'est parce qu'il y a une certaine crise—notamment en ce qui concerne les matières énergétiques et les matières premières—que le problème de l'environnement et les problèmes de recyclage semblent prendre de l'acuité. Mais reconnaître qu'il faut une crise pour chercher à résoudre ces problèmes est un constat d'échec. Il serait donc souhaitable que la conférence puisse appeler l'attention sur le fait que les décisions ne peuvent pas être de simples solutions techniques. Je sais que cela peut dépasser le cadre de cette conférence mais je souhaite que cela ne dépasse pas le cadre des compétences et des objectifs de l'Institut de la Vie, toute la Vie.

ROY: J'aurais 3 cas de recyclage à signaler: Premièrement, la construction d'un incinérateur dans la ville de Québec d'une capacité de 1000 tonnes récupérant la chaleur sous forme de vapeur qui est utilisée par une usine de pâte à papier. Le deuxième cas, est l'utilisation de 1000 tonnes par jour de déchets de scieries qui sont réutilisés pour faire de la pâte à papier. Le troisième cas est l'utilisation de l'anhydride sulfureux rejeté à l'atmosphère par un "smelter" (usine d'affinage de métaux non ferreux) pour produire 1000 tonnes d'acide sulfurique par jour.

HIGBIE: I don't know if there is a single paper that has compared the actual costs of each of these individual demonstration units that I mentioned. We have evaluated the costs of our own Bureau of Mines' process and I'm sure that the gentlemen from Black Clawson can talk about the costs of his process. There is a speaker here from St. Louis, Missouri, who may talk this afternoon about the costs of the Union Electric Process. But from our own Bureau estimations, for the process we have developed for treating raw refuse, if the technology is expanded to 1000 tons per day without colored-glass separation, we believe that such a plant would cost \$3.4 million. We estimate that one can operate that plant at \$2.70 a ton of input material, that you can obtain \$9.80 worth of valued products and save \$3.00 in landfill operations. I can give you further details of what costs are involved in the process, but I don't think that I should take the time of the whole group right now to do that.

PETROLEUM AS A NON-FUEL RESOURCE

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Products that man produces from petroleum and natural gas now are essential to the basic food, shelter, clothing, and health needs of every nation in the world. Yet, when the world's resources of petroleum are considered, no effort is made to assign a high priority to petrochemical feedstock used for the manufacture of synthetic fibers, pharmaceuticals, agricultural chemicals, synthetic rubber, and plastics. Although all of these products could theoretically be manufactured from other raw material, the technology for such processing has not yet been developed. Furthermore, at the present time the cost of going to more basic forms of carbon (e.g. coal or CO_2) to produce these materials would make it economically prohibitive for these products to be used in the volumes in which they are consumed today.

In examining the per capita consumption of basic minerals, petroleum, timber resources, and other so-called "replenishable", or grown, natural resources, we find virtually a static condition on both a world and country by country basis. However, the per capita consumption of synthetic materials—including such materials as plastics, elastomers, man-made fibers, agricultural chemicals, and pharmaceuticals—we find a rapidly rising growth curve over the last 25 years. The largest raw material feedstock for these products comes from petroleum and natural gas resources. At the present time the world is utilizing an estimated 3% of these resources as petrochemical feedstocks. In the United States approximately 6% of our petroleum and natural gas is converted into products rather than consumed as fuel. It is estimated that the petrochemical products manufactured from this small quantity of feedstock has a market value of approximately 15 times the value of the refined petroleum products made from the other 94% of petroleum and natural gas products consumed as fuel and refined petroleum products.

In projecting the demand for petrochemical based synthetics into the future, it is estimated that the percentage of total petroleum consumption going to such uses could easily triple or quadruple before the year 2000. Such an increasing percentage of petroleum going into non-fuel uses is likely to occur only under the following circumstances:

First, that there is an adequate world recognition that petroleum has a greater value to man as a non-fuel resource than as a fuel resource.

And second, that there is a substantial start made in the development of other sources of energy to meet the world's long-term energy needs.

Both of these changes must evolve from the recognition that the world's material needs and energy needs are highly interrelated.

The basic laws of thermodynamics teach us several things: first, that man can create

neither material nor energy—he merely converts materials and energy from one form to another—and secondly, that the basic free energy of the world is continually decreasing. Eventually, as the world ages it will become a cold inert planet unable to support life as we know it today. Man can accelerate this demise of our planet, and does, by the purposeful destruction of complex natural materials merely for the release of energy.

The only new energy we can rely on to extend man's existence on the earth is the radiation we receive from the Sun. But there are many other forms of natural energy—including nuclear, geothermal, hydroelectric, and tidal energy—that should be developed to meet our full energy needs.

The conclusion we can draw from understanding the basic laws of thermodynamics and relating them to our material and energy needs might be summarized in some basic guidelines for use in planning for the future:

1. Avoid the destruction of naturally occurring complex chemicals (such as petroleum, coal, wood, cotton, and wool) in their first use merely for the release of energy.
2. Attempt to use all complex chemicals at as nearly their original level of energy as possible and consider the thermodynamics of recycling them as many times as possible before eventually recovering their energy value through oxidative degradation.
3. Attempt to use natural forms of energy—nuclear, geothermal, solar, hydroelectric, tidal—in preference to the recovery of the entropic energy of material.
4. Develop techniques of selecting the most thermodynamically efficient materials to make particular products.
5. And finally, the most challenging requirement is to build the economic incentives necessary to direct petroleum into material applications as their first priority usage rather than for fuel. This incentive can be most easily accomplished by the development of new sources of energy that will be lower in cost than energy from petroleum.

EFFECTS OF THE RECYCLING OF WASTES ON NON-RENEWABLE RESOURCES

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BASIC ASSUMPTIONS

1. In its true sense. Waste is a mode of conduct.
2. Waste in its material sense is a misplaced resource.
3. All resources can finally be expressed in terms of energy.
4. The concept of total energy is a sound guide to resource use and reuse.
5. Freedom of choice is a common regulator. Need the final regulator.
6. Choice is governed by the recognized laws of supply and demand.
7. The law of supply and demand with few primitive exceptions is exercised through the monetary medium. This suffers from maldistribution, restricting choice, aggravating need.
8. The propensity to spend or save whether governed by free choice or other causes determines the monetary flow.
9. The monetary medium/flow is finally flexible.
10. Primary resources less so, finally not so.

The fundamental approach to resource use reuse must first acknowledge these basic assumptions.

The recycling of resources and the avoidance of wasteful practice is scientifically, socially, and economically demanding cold analysis ahead of emotive pressures.

This is not to deny compassion as the heart dictates or passion as justice demands. It is clearly to seek justice between man and his environment, including his fellows and heirs, with a measure of recognition, injustice is and will be present, for we do not live in a perfect world.

MATERIAL ASSUMPTIONS

1. All resources employed in the production process, transferred to utility and discarded after use, are contaminated one with another in some degree.
2. Extraction, process, manufacture and assembly, discard and collection after use, all contribute to the resultant impurity common to that which we term waste.
3. Recycling in its pure and perfect sense demands that all contaminants be removed one from the other at every turn of the cycle if there is not to be a further progressive contamination in time to the detriment of the resource/resources recycled.
4. This is not possible and therefore the product termed waste can for convenience be best encompassed in total as a low-grade ore of mixed variables.

5. A common denominator can here be usefully employed. The calorific values expressed in BTUs or their equivalents, as best this can be determined, appears to provide a sensible unit.

6. From this, all along the line, primary resource, utility object, discard after use, BTU values can be established with sufficient accuracy to provide for the employment of what is termed the energy equation.

7. To determine the justice of recycling, taking the term justice to mean the best possible relationship between resource use and resources available, the BTU cost of primary resources from source to utility inclusive and the BTU values within the area termed waste less the BTU cost of returning to point of use/reuse, are the principal governing factors.

8. A return to reuse in any form is justified if the energy cost of return is less than the total energy value of the waste product returned.

9. The monetary cost/benefit will adjust to the marginal factor at point of reuse.

10. The social need may prohibit natural adjustment by monetary means where the scarcity factor approaches known fixed limits relative to present and future needs. In such event economic certainty based upon scarcity will not exist.

The material assumptions above described will suffer adjustment in areas indefinite as to man's ingenuity, and will to survive, preferred socially, finally, man against man.

MATERIAL CERTAINTIES

1. If there is no waste there can be no pollution. The feed-back cost of pollution should therefore be added to the value of the product termed waste. Pollution should here be taken in its widest sense, i.e. the impact burden of waste—social and economic.

2. Waste is contained in any resource transferred to the areas of utility and discard after use that is not in either area beneficially employed.

3. Thermal loss in excess of solar input represents a total loss.

4. Other than clean salvageable items the properties of the product termed waste cannot be expressed or recycled by practical means in purity. They can be expressed for the purposes of recycling in terms of their organic, inorganic, and toxic composition. The latter of necessity.

5. The bulk of the product waste can normally be expected to appear in three conditions, liquid, semi-liquid, and solids. All in some degree intermixed. Thermal radiation, atmospheric dust, and radioactive wastes are also present.

6. Further classification recognizes the waste flow as normally following three main paths. Industrial, consumer (domestic), and agricultural.

7. Liquid and semi-liquid (sewage), agricultural and mining wastes are substantially detached from the industrial commercial domestic refuse flow. These will be dealt with separately outside this paper in other submissions.

8. This present submission will now centre upon the common refuse flow embracing finally, domestic and trade refuse through various systems.

9. Industrial waste is in large measure home scrap recycled at source, toxic waste, best controlled at source and mixed refuse that can be either accommodated at communal facilities or at a facility installed at the industrial unit.

10. This submission will deal with technology applied and on stream directed towards

the communal facility (domestic and trade refuse) of benefit to the resource use reuse pattern, ahead of past habits centred in the main, on disposal.

The material certainties above described are labelled certain to provide for practical analysis and application and to here give positive movement at the optimum level ahead of continuous penetrated study seeking perfect solutions that may or may not be realized. As in all areas there is here a point of balance.

TECHNICAL CONSIDERATIONS

1. Technology should preferably embrace best known, allied to good practice, maximum social economic benefit, good sense, common need and particular circumstances.

2. The unit of quantity can conveniently be expressed in thermal units. The unit of quality, the social benefit. The unit cost in monetary terms.

3. The profit motive, if not always by wish, most common in fact, exists as the prime motive force relative new technology. Public health and hygiene are substantial motives of first consideration in limited areas. The environmental cost/impact is the principal area for debate.

4. The common refuse stream is generally calculated at a recovery value 5000 BTU/lb. Some 90% of this is contained in the organics fraction.

5. Substantial product yields in the form of metals (ferrous and non-ferrous) and glass exist in the inorganics fraction to justify recovery by known technical means.

6. The paper fraction at this moment in time is worthy of recovery as paper, albeit soiled, and probably into the future having regard to de-inking and paperstock treatment processes now established. Woodpulp is not, however, a finite resource, the photosynthesis characteristic of forest growth provides a free energy source. Improved forest culture and harvesting indicates a more favourable condition in time as to the supply of woodpulp. This is not, however, expected to adversely affect the continuous demand for paperstock.

7. The balance of the refuse stream can for the moment best enter an indiscriminate flow to final process. This is mainly organic, dust, and fines.

8. The plastic element, other than home scrap, does not justify pure recovery at present levels. It has a high thermal value (approximately 16,000 BTU/lb) which can be recovered by known combustion processes.

9. Dewatered sewage sludge at D.M. 20% plus justifies recovery ahead of disposal, the latter a major environmental problem. This can be directed to final process allied to the domestic refuse stream or to other ends.

10. Final process for the domestic refuse stream includes:
    - (a) Controlled landfill. Least cost, proven method, total loss, limited potential now visible in certain urban situations.
    - (b) Common incineration. High cost, total loss, residue doubtful value.
    - (c) Boiler feed. Thermal value varied and in doubt due to variable nature and conduct of feed input. Possibilities, thermal yield demands certain market.
    - (d) Pyrolosis, total or partial. Seeming best potential. End products oil and/or gas, char. Demands effective utilization net gas yield.
    - (e) Fluid bed combustion. Preferred next. End product gas, char perhaps. End product gas as for pyrolosis.

(f) Composting. Marked obstacles at the market. Adverse factors present in trace metals and toxic element (occasional present). Probable improved market in time relative increased cost/scarcity phosphates and other plant foods. Best present potential under developed countries.
(g) Micro-culture. Adverse factors as per composting. Certain specific cultures under study. Potential allied to other work in areas detached from the common refuse flow. Believed to be benefits in time. Pollution factor (water courses) probable. Treatment process relative here need.
(h) Hydro-pulping. Varied applications, uncertain potential cost/benefit. Pollution factor as per micro-culture.

The technical considerations above are described allied to a known and accepted waste pattern present common to the developed countries and to technology known to be capable or potentially so.

FRONT END SYSTEM

1. The common refuse flow does not realize a product of known certain composition It can and will be varied one situation to the next and as a result of changes in the resource use pattern. The product waste also contains materials of varied bulk, structure and density.

2. Municipal Solid Wastes (MSW), to employ the American term, are, however, within a range of consistency that can be accommodated by a single front-end dry separation system. The necessary technology exists, some old established, the balance well tested in the prototype and pilot-stage areas.

3. The final design of the front-end system must contain a degree of flexibility to accommodate not only the varied consistency and constituents of the product waste but also variable conditions at the market for the product yield.

4. There is ample evidence to show, a simple flexible front-end dry separation process can and should be applied to MSW to recover the metals, glass, and aluminium fractions. Also the paper fraction at any level demanded.

5. Perfect separation is not necessarily best process. There is an optimum level having regard to investment/operational cost and product yield. Modular construction to optimum design specification is to be preferred.

6. Certain technology now being entertained in this area is in my view unnecessarily complex. My present research indicates a simple single unit with limited attachments based on the old farm grain separator having an optimum capacity 10 tons/hour may well meet the need.

7. Where a thermal combustion process is employed to accommodate the organics fraction the air-separation capability employed at the front end could conceivably contain any consequent thermal radiation and certain loss from the combustion unit. This could be transmitted to the front end to introduce a drying capability within the separation unit.

8. Whatever the final technology applied it must be certain positive and preferred simple. The refuse stream is constant and unavoidable if varied in its nature and construction. There is a final and social burden upon any process and all persons concerned in the area of waste management to accommodate the communities wastes. Extended shut down from any cause is socially intolerable.

9. No technology is foolproof therefore fail-safe conditions must be installed all along the line to accommodate failure within acceptable agreed limits. This is possible. Any

technology employed should provide for comparative simple on-site service and repair within a time factor acceptable, say 10 hour maximum.

10. Where the TRC (Total Reclamation Centre) is operated by private interests, there must be provision to allow for the municipal authority to secure certain and immediate right of access in the event of any failure on the part of the private operator, from any cause, that gives rise to a bottleneck in the waste stream.

MARGINAL FACTORS

1. In applying technology to the recycling process I start with the assumption there is no profit in waste. I do so because any benefits to be secured from recycling are dependent upon a process of recovery that can be economically employed.
2. To determine the values in the waste stream is a pointless exercise if these values cannot be recovered to social/economic benefit. Sufficient data, if non-exact, has now accumulated from a number of sources to indicate the probable constituents of the waste product.
3. To calculate the value of a pile of garbage is, however, not good enough. We must recognize the waste stream exists from first extraction at primary source through process, production, utility to discard after use.
4. Assuming waste is not a tangible product but a mode of conduct, waste avoidance demands preferred utility all along the line from primary source to discard after use with a firm eye on thermal losses. This calls for input savings, efficient process best design, economic production, and maximum utility.
5. Because it is not technically possible to economically sustain a perfect transition at any point along the line from primary source to ultimate utility there is at all points an unavoidable material residue we term waste, i.e. the waste product.
6. This product is recoverable in some degree, thermal losses are not. The marginal factor is established at the point where the value of one unit of the waste product recovered exceeds the cost of its recovery and at the point where the thermal value of one unit lost to atmosphere exceeds the thermal cost necessary to restrain such loss.
7. Ultimately the marginal factors can preferably be stated in terms of energy rather than in monetary terms by virtue of the fact energy is an exact commodity whereas money is a flexible medium. In effect resources require an energy standard in the same way as the monetary unit employs the gold standard.
8. This is technically possible but not yet convenient for we need a great deal more data based upon the energy equation before satisfactory references can be made.
9. The factor of scarcity relative finite resources has also to be acknowledged particularly where substitution is not readily available to the element of choice.
10. There is ample evidence to show a substantial portion of the waste stream can be recovered at unit cost below the margin. All cost/benefits must be acknowledged in every assessment—for example, disposal costs as an alternative to recovery.

As in all areas of investment, the marginal factor must be entertained when new technology is applied to the waste stream. This is obvious common sense and would not be stated but for the need to restrain promises in the technical area directed towards the emotional pressures relative primary resources as distinct from the true pressures improved technology can satisfactorily contain.

SYSTEM DESIGN GUIDELINES

1. Within the developed countries the common waste-flow pattern and choice of technology can generally be set with some accuracy against a given population factor. There is some variable between the E.E.C., U.S.A., and Japan. This can be accommodated within the technology described.

2. Best technology should seek to realize a standard module at optimum level against a given population factor to meet situations most common. One-off solutions are not likely to realize maximum benefit overall having regard to the base reference, total energy.

3. The standard module must embrace a degree of flexibility as to volume/quality refuse flow and exact technology. Fail-safe conditions must be present for the refuse flow is certain. Bottlenecks are not socially tolerable.

4. The refuse flow is determined by resource use. The under-developed countries therefore present a separate waste problem. It is in the main restricted to sewage and putriciples in densely populated regions. A separate design module may here be required.

5. Design and manufacture will in time adjust to aggravate improved resource use/reuse, savings at source and in line. This will lead to an extended life use of utility products and/or designed obsolence directed to recovery and reuse beyond first use.

6. Improved means in these areas will progressively affect the domestic refuse-flow pattern. It may expand or contract. Quality/quantity will in the event suffer adjustment.

7. Technology transfer in all areas of resource use extending to utility and recovery after use will have a bearing upon the waste product in time.

8. Any shift from consumption to conservation will affect the refuse-flow pattern.

9. A will to economic growth ahead of restraint will probably remain present. Indiscriminate use of primary resources should not be allowed to support this. New technology in seeking new boundaries must acknowledge and adapt to known limits existing and likely to arise.

10. The quality of life is now recognized as of growing importance. Here advocacy and technology will no doubt conflict. The right point of balance must be sought at personal, community, national and international levels.

System design must acknowledge, technical development will persist in the wider field. This will affect the waste product which itself will attract new technology centred upon recovery and recycling.

Continuous monitoring and analysis leading to preferred agreed solutions in all areas of technology, resource use, and reuse can have a marked bearing upon waste avoidance.

The immediate need is to set known proven and seen potential technology suited to waste recovery and recycling against disposal practices previous and at present common.

All system design in this area must acknowledge waste disposal ahead of recovery is no longer acceptable.

Whereas the energy equation is the desired base reference, economic guidelines will probably remain dominant for some time to come.

DISCUSSION

COLON: Mr. Chairman, perhaps I may give something on the question that was raised this morning: How can we promote recycling? There is an example in the Netherlands and I feel it is perhaps helpful to say here how recycling may be started by legislation. More than 40 years ago, we had a serious environmental problem in Holland in that the bodies of cows and pigs that died by diseases were buried by the farmers on their land itself. When recognized that this gave serious infection risks, the government made what is called and translated into English, "The Destruction Act". According to this Act, several plants were constructed to process the animal bodies. The farmers had to deliver the dead animals to the collection services of these plants. It turned out to be a profitable operation and now private companies are doing this job. Selling a lot of valuable products and the most important part of it is animal feet of a high protein content. I am not informed whether in other countries the same was done.

SCHENKEL: J'ai 3 questions pour les experts. 1°) Comment jugez-vous les influences de la pollution secondaire de l'environnement par des processus de recyclage?

2°) Comment jugez-vous l'influence de l'entropie sur le processus de recyclage? C'est-à-dire que lorsque vous transformez de l'énergie d'une forme primaire—par exemple de l'électricité—dans une forme secondaire la chaleur, la distribution des matériaux va s'aggrandir. Par exemple, il est très facile de dissoudre du sucre dans du café mais il est très difficile de séparer ensuite le sucre du café.

3°) Le recyclage du papier par exemple est limité pour des raisons techniques. On estime en République Fédérale Allemande que 50% de papier peut-être recyclé. Mais quand l'usage du papier s'accroît également, la quantité de papier dans les ordures ménagères s'accroît.

MACLAREN: Mr. Chairman, I understand that this conference will produce recommendations and is, in effect, hopeful of influencing legislation in many countries, perhaps influencing thought. Today we've discussed waste and waste disposal, and I'd like to make a general comment. When I have a cup of coffee in North America, I unwrap the sugar and put it in a polystyrene cup. I take a cardboard waxed container with cream and a plastic cover, and a plastic stirrer—all of which are thrown away. We buy motor cars and refrigerators which have a short life because they are badly built. Do we consider waste disposal in terms of production of machines and goods that are necessary? If they are necessary, do we ask whether we can't make them better so that they last longer? I know that this is an heretical economic question, but I do feel that in terms of waste disposal we should examine what the waste is as well as how we dispose of it.

BROWN: Thank you. I think you've raised a very important point and I know that in certain kinds of restaurants, chain restaurants, where you can drive in and buy a hamburger, the energy content of the material which is thrown away—the paper napkins, the containers, etc.—is greater than the energy content of the food. Are there are other comments?

RUBIN: How can we bring about a situation in which the desirable recycling practices are accepted generally and permanently enough to be significant? It seems that three major ways are available to us: one way is to make recycling sufficiently profitable to all the individuals and economic entities which must participate in the recycling chain; the second way, already mentioned here, is legislation; and a third way is based on education, which would have to create social pressures sufficiently strong to induce participation of the people and companies required by the recycling process. It seems that the last way is a rather long-range kind of a way and if we want to introduce recycling relatively quickly, we must depend largely on the first two ways. From a technical point of view (and after all this is the point of view which we are supposed to take here) it seems that an important question which should be answered here is: to which degree does it look that by utilizing the best in our current technology we can rely on the first way, the profit motive, and to which degree and where must we legislate? My question is: are we ready to give such a technical advice?

HIGBIE: I think there is little doubt that if metal recycling can be made profitable, the industry will play its important role. It has been suggested that a chicken and an egg situation exists; as metal recycling technology develops, so will the markets, and thus eventually both the industry and the consumer will benefit. However, I think a certain amount of legislation to help sponsor recycling technology does have to be passed. There's been some discussion in our country as to whether it should be federal legislation or local-level legislation. At the moment, there is no decision on it. There are many possible laws in this area considered by the Congress of our federal Government. But they have not been passed as yet. So therefore, to be most effective immediately, legislative action should be taken by the cities or by the states, or other political entities. I think that's the areas where the greatest support of recycling is going to come from eventually. But it is not going to be as simple as that. Education of the public is a very important factor. I think you've expressed the three major items. There has been concern as to whether we can effectively separate materials while the refuse is still in the households (source separation). I've seen situations in Europe where your people are doing a much better job than that which is taking place in some of the U.S. cities. The mayor of Chicago once voiced an opinion when he was asked, Would his people separate refuse into its individual components at home? His answer was: "Separate it, We're lucky if they put it altogether into a bag and leave it where it can be collected." He didn't think people in Chicago would be in favor of

source separation. So you see education of the public is a major item. In general, I don't think there is any one panacea to solving the problem.

BROWN: Thank you very much. Before we adjourn I'd like to bring up a very important point. During the plenary session the Vice Chairman of this session and I must report on what we talked about. We are going to have to work on that tonight. In addition it's going to be important, I believe, that we be in a position to make some concrete proposals to the plenary session for them to consider.

McKELVEY: Thank you, Mr. Chairman. It occurred to me during our discussion yesterday that there was quite a bit of consensus about many of the problems in this general area. Last evening I jotted down some propositions that I thought perhaps this group might wish to consider, modifying them as you see fit and perhaps if there is consensus on these or other similar propositions, they might be then given to our co-chairman to pass on to the plenary body when it meets during the remainder of the week. If I have the Chairman's permission, I will read these half-dozen propositions and I offer them merely as that, merely as suggestions for propositions on which consensus might be reached. I have copies available here on the front table for anyone who may wish to pick one up. The first is that developed countries should aim towards reducing their rates of increase in consumption of minerals, water, and mineral fuels and seek to support further economic advancement through increased efficiency and the production and use of these vital materials. Second, governments and intergovernmental bodies should endeavour to raise the level of living of impoverished peoples in both poor and rich countries through improved means of distribution of income, efficiency, and use of resources and other means that do not increase world consumption of minerals, water and mineral fuels. Third, governments and intergovernmental bodies should vigorously encourage the processes and activities by which resources are created and extended as through scientific research, exploration, prevention of waste, recycling, and conservation in use. Fourth, governments and intergovernmental bodies an d the peoples of all countries should strive to prevent further growth in world population and to bring world population into equilibrium with the earth's and man's supportive capabilities. Fifth, governments' intergovernmental bodies, and private institutions should dedicate themselves to the advancement of the knowledge and skills of the people of the world in order to enhance their abilities to utilize the earth's resources efficiently and wisely, to maintain a safe and satisfying environment, and to enhance the quality of life for present and future generations. Sixth, governments and intergovernmental bodies should take steps to appraise potential resources and to examine possibly imbalancing resource, environmental, and population trends in order to anticipate and avoid chaotic consequences of resource development and of economic and population growth. Thank you, Mr. Chairman, perhaps we can discuss these later on?

Chapter IV

ENVIRONMENTAL EFFECTS OF WASTE MATERIALS

CONTENTS

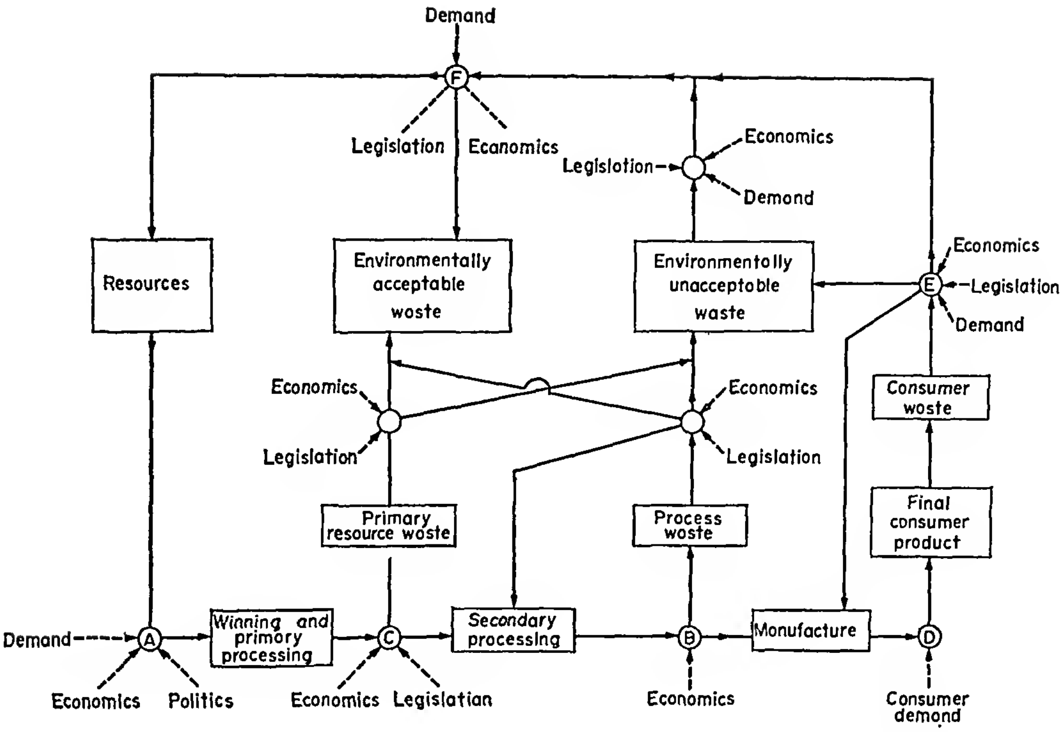

Fig. 2

that material enters the system from some resource supply and leaves it as a new resource, or in a form which is environmentally acceptable or in a form which is environmentally unacceptable. In principle the form may be solid, liquid, or gas; as an extreme case, carbon

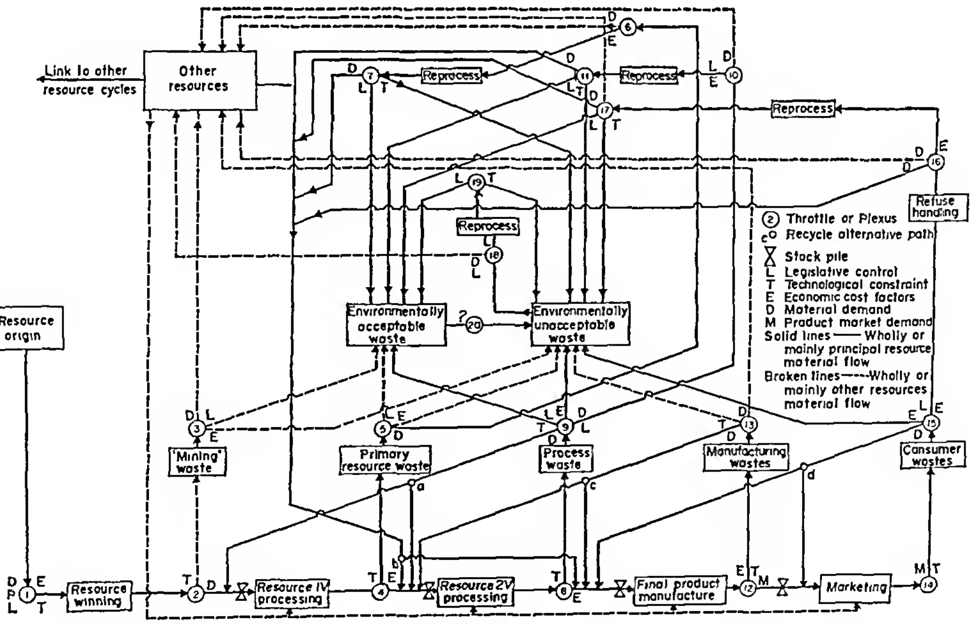

Fig. 3

monoxide or dioxide originating from an organic resource may be acceptable or unacceptable according to the atmospheric pollution created.

At critical points in the system the flow is limited and/or directed by a throttle or plexus, the settling of which is governed by controls. The main controlling factors are Demand, Economics, Legislation, and Politics. For the sake of brevity, legislation is here used in a very broad sense to cover true legal constraints, public opinion, maintenance of public goodwill, and simple conscience. The processing and manufacturing stages are highly simplified. The subdivisions shown are only to demonstrate the general differences between wastes arising from the main stages. Most primary process wastes are unfit for direct recycling back to the previous stage and in fact originate from the internal reprocessing of material in the processing plant. Many wastes in secondary processing return directly within the plant, but many others—notably, the rich slags and drosses from metallurgical operations—accumulate outside the plant and re-enter at a different point, or by a different route, or even by a different industry. The flow sheet is thus the summation of the flows in all of the industries using the given resource. Consumer wastes seldom re-enter the circuit directly and even more seldom re-enter directly at points earlier than the manufacturing stage. The notable exceptions are items such as returnable containers and clean paper, "tin" foil, etc. The majority of the recycled consumer wastes need special processing to such an extent that on a simplified flow sheet such as Fig. 2 they can be linked to primary resource. Figure 2 does, however, serve to show the basic framework which has been developed in Fig. 3.

The principal features of Fig. 3 which distinguish it from Fig. 2 are:

1. The introduction of flows into and out of the main specific resource circuit of materials belonging to other resource circuits;
2. the elaboration of the reprocessing routes by which wastes are reprocessed to yield materials (a) for recycling to the main resource circuit, (b) for recycling to other resource circuits, (c) for disposal to the environment as acceptable wastes;
3. the subdivision of the process route into the minimum number of processing stages needed to identify the major waste sources and recycle points.

The "Resource origin" is strictly a virgin source; an ore-body, a forest, a rubber plantation, an oil-well, etc., but the term "main resource" is used to denote the material flowing in the particular cycle under consideration. By this definition all products which leave the main resource stream are wastes, even though they may themselves be the origin of another resource cycle. Rate of flow of material from the origin is governed by the throttle (1), which is mainly controlled by the demand for the resource in relation to the economics. Various legislative controls can also operate which may be based on resource conservation, national economy policy, or for environmental reasons. It is not unknown for the overriding control to be solely for political reasons. Sufficient technology must be available to win and process the resource for the desired end-product; if the minimum necessary technology is available then only the cost of the technology is involved in the exploitation decision. The control equations are therefore of the form

$$dM/dt = f(D) + f_2(E) + f_3(T) + f_4(L) + f_5(P)$$

where all terms except $f(D)$ and $f(T)$ may be either positive or negative and must also include contributions from other resource material flows coming from the same origin. Mining waste is considered to be any bulk product which has to be taken directly from the origin at the same time as the main resource. Commonly it is almost barren in respect of

the main resource, but both the quantity and the grade (content of the main resource) may be influenced by the technology employed and by the demand at plexus (2). If there is a demand for it in its own right as another resource material then it leaves the cycle and any further processing, economic, and disposal problems become the responsibility of the other resource cycle. The plexus (3) indicates that if the demand is zero or less than the quantity produced then all or part of it must be rejected to the environment. The nature of the waste and legislative/economic controls dictate whether or not it can be acceptable. No reprocessing—even for environmental reasons—is shown because if it does contain any main resource then if the constraints on its disposal are large it will join the main flow to the primary processing stages of the treatment plant. This will not affect the overall mass balance in the process circuit, which is temporarily increased following plexus (2) by the first entry of true recycled material. There may also be further imbalances in feed at any time due to stockpiling of crudes. The total mass of *all* material flowing in the circuit may be increased by the addition of other resources needed to process the crude. Thus, the wastes from the primary processing may contain or be in parallel with other resource waste streams. The nature and quantity of all of the primary waste streams is controlled at plexus (4) by technological (the process) and economic factors. No direct recycling is shown because any products of treatable grade can be regarded as intermediate products for processing within the treatment plant (e.g. scavenging of rougher tails). The primary wastes leaving the plant are subject to further control at plexus (5). If there is a demand for the content of other resources the wastes may go (via plexus (6)) to the other resource cycle. The responsibility for reprocessing it and subsequent disposal of subsidiary wastes then devolves on the processor of the other resource. If the wastes are unacceptable for discharge to the environment and are subject to legislative or strong opinion control then there are two other immediate choices open. These depend upon the grade, content of other resource, and the result of another $f(L), f(D), f(E), f(T)$ calculation (this time to minimize the unprofitability of the operation). Commonly, minimum unprofitability is achieved by further processing (or process modification) within the existing plant. If the grade is too low or the processing required is essentially different then the wastes must pass to an "external" processing plant. A further choice is available at plexus (6) which depends on the economic balance between reprocessing mainly to recoup some of the cost from the sale of the other resource content(s) and reprocessing to recover the main resource material content. Following the convention stated earlier, the former is not shown within the main cycle on the principle that it is the chief beneficiary who should carry the responsibility and cost of the environmental damage. If the grade is high enough, or the other resource content unsaleable, then reprocessing will be done within the resource cycle. The object will be to return to the main cycle as much as economics and technology will permit at the same time the production of an acceptable reprocessing waste. Inevitably, there will be some fraction of the reprocessing wastes which will still be unacceptable. It is extremely unlikely in view of the number of earlier decision points and the problems of reprocessing that any wastes arising at plexus (7) will have value in another resource cycle. The value products from the reprocessing will probably return to the cycle at the secondary processing stage; it is less likely that they will be able to go forward to the manufacturing stage and improbable that they will re-enter as early as the primary processing stage.

The constraints on the flow of wastes and products from the resource secondary processing stages at plexus (8) are similar to those at plexus (4). Again, a mass imbalance may be found due to recycled and stockpiled material. The process wastes generally differ from

the primary wastes in resource value content and in nature. However, some of them may contain a much larger content of other resources introduced during processing. The greater sophistication of the technology employed offers more options in adjusting the process (back-reaction from controls at plexus (9)) to produce wastes suited to the control demands. Some unacceptable waste is almost inevitable and the combined pressures of economics, legislation, and technical problems may result in the acceptable waste still having a relatively high content of values. From plexus (9) onwards through (10) and (11) the situation closely resembles (6) and (7) with the exception that the higher values content offers a greater incentive for reprocessing. There is usually a high recycle rate within the process—therefore not shown—much of the other waste is reprocessed in a different plant on-site within the industry and some may need to return to as additional feed to primary processing.

In final product manufacture the largest loop is commonly return to secondary processing. The grades are usually so high that the bulk of the streams containing values return very quickly to the cycle. Similarly, the contents of other resources are commonly so high that these pass to other resource cycles. The remaining route from plexus (13) consists of complex wastes which are low grade and are mixtures of other components and resource materials. These are invariably unacceptable and, if treated via plexus (18) and (19), are usually reprocessed, as the result of legislation and only after escaping from the plant.

The marketing stage includes packaging, advertising material, and distribution. It is therefore an important source of wastes arising from the input of other resources, which nevertheless are directly associated with the consumption rate of the main resource. The quantity of such wastes is controlled by market requirements which are a function of the demand, customer appeal, and product specification. Similar constraints applied to the manufacturing stage, but with less effect on the nature of the manufacturing wastes. Customer appeal also contains factors relating to obsolescence rate. The throttle (14) is therefore usually the most important rate-determining step within an industry both for main resource and supplementary resource usage and for waste production. It is the point where minimum pressure on the controls can have maximum overall effect. All of the material passing through (14) is sooner or later a waste. Plexus (15) indicates that some of the waste may return directly to the cycle; it is a moot point whether the return should be shown as a solid or as a broken line. Returnable glass bottles would be a main resource for flows in the glass industry, but a supplementary resource in the brewing industry. Whatever it may be, the direct recirculation loop implies selective handling or sorting before the wastes escape to the external environment. Consumer wastes at this stage which are directly acceptable for disposal to the environment without further handling are rare enough to be ignored. Various controls, including problems of separate collection, etc., direct a major part to a refuse-handling system. The type of refuse-handling plant and the fate of the products is determined by the controls acting at plexus (16). At this point two arbitrary decisions have been made. One is that the refuse handling is defined as confined to simple sorting (possibly including shredding and baling) and the other is that tipping—even of sorted refuse—is not acceptable. The latter is currently, legitimately debatable particularly from a short-term viewpoint. However, with these assumptions the principal control is the demand for the resource materials. The main resource, if a rich enough product can be sorted from the refuse, returns to the cycle at an appropriate point. Other resources going to other cycles may or may not be rich enough to return directly, any necessary reprocessing is, as before, to be included in the other resource cycles. The remaining refuse now

follows pathways through plexus (17) similar to those of the earlier wastes; only the magnitude of the controls and the emphasis may differ. The principles of attempting to maximize the fraction utilizable and to minimize the production of unacceptable reprocessing wastes remain the same.

The subsidiary loop (18) through (19) has been mentioned as a pathway for the conversion of unacceptable manufacturing wastes into acceptable wastes, but it is mainly the route by which existing dump of unacceptable mineral waste are converted into acceptable waste mainly under the pressure of legislation and opinion. Plexus (18) allows for the reprocessing of the dump material for other resource needs. It is possible that main resource values which have escaped the other reprocessing pathways may be recoverable to give a values product at plexus (19) during reprocessing for environmental reasons. It is far more usual in environmental reprocessing to attempt to reduce the cost by finding an outlet for the bulk of the waste. Dumps large enough and/or rich enough to warrant reprocessing for values are best regarded as secondary origins for the purpose of attempting mass flow balances.

Throttle (20) allows for the possible future reclassification of a waste. It can be neglected for present flows, but must not be forgotten if forecasts are wanted.

Despite the obvious impossibility of describing all material cycles in one diagram, the present flowsheet does cover the majority of cycles of interest.

The object was to make it possible to set up mass flow patterns for industrial operations using a specified resource in such a way that the operations could readily be summed to give a resource utilization/recovery/waste balance. Ideally, the steps are to identify the flow paths relevant to the operation, evaluate the flows in each path and then to sum the flows in the paths. It may be expected that some flows may need to be calculated from network theory. The numbered circles represent rate-determining steps, thus leading to a dynamic model. Even without the model, it appears from the flowsheet that the best compromise between throttling down the flow of waste and adversely affecting the process industry is to apply controls starting on the right-hand side of the flowsheet. It is also apparent that excessive control applied, for instance, at plexus (9) could have an almost disastrous effect on the cycle without necessarily achieving much in the way of overall gain in environmental conditions. The interactions which produce this effect are by no means solely due to the disturbance of the mass flow cycle.

The effect is also due—possibly more importantly—to the fact that the control factors, operating at the rate-determining steps, are themselves in an economic network influenced in turn by policy decisions. It is not intended to investigate the economic network, in this paper. It is considered that any attempt to rationalize the interactions between resources, wastes, and the environment must start with the systematic evaluation of the mass flow balances and rate constants. Until these are known, it will be virtually impossible to assess the overall effect of imposing or modifying controls at any one point.

CE QUE NOÛS COUTENT LES DÉCHETS EN FRAIS, EN PERTES DE VALEURS IDÉALES ET CULTURELLES ET EN DÉSAVANTAGES ÉCONOMIQUES

WOLFGANG MOSER

Secrétaire général de la Ligue pour la Propreté en Suisse, Zurich, Suisse

INTRODUCTION

Permettez-moi de commencer mon exposé par l'énonciation de trois faits bien établis:

Fait No. 1

Tout ce que l'homme prend de la nature, tout ce qu'il travaille, transforme et utilise finit, tôt ou tard, par devenir déchet.

Les déchets, qui peuvent être solides, liquides ou gazeux, sont donc une des conséquences inévitables de la vie de l'homme sur cette terre. Depuis qu'il y a des hommes sur notre planète, il y a eu des déchets, et tant qu'il y aura encore des hommes sur notre planète, il y aura des déchets. Rien n'a changé ce fait au cours des siècles—seules les quantités et la nature des déchets ont changé, et cela surtout depuis l'avènement de l'ère industrielle.

Fait No. 2

Selon une loi de la nature—la loi de la conservation de l'énergie et de la matière—il a toujours été et sera toujours impossible de détruire les déchets.

Ils peuvent seulement être transformés en d'autres matières solides, liquides ou gazeuses.

Fait No. 3

Chacun des processus de transformation résulte en charges imposées à l'environnement. Malgré les progrès de la technique, on ne réussira sans doute jamais à éviter eomplètement de grever ainsi l'environnement.

Toutefois, en optimisant la gestion des déchets et au prix de frais énormes, on arrivera—et il faut absolumenty arriver—à réduire ces charges dans toute la mesure du possible

TABLEAU 1.

Flux et traitement des déchets	Frais directs	Frais indirects	Pertes en valeurs idéales et culturelles, désavantages économiques
I. DECHETS SOLIDES			
Production de déchets communaux (ménages, commerce, etc.)	frais d'encombrement (m³), frais pour les récipients (corbeilles à papier, sacs, seaux, containers, etc.)	frais de traitement des déchets résultant de la production des récipients à déchets (déchets de production)	de peu d'importance; éventuelle diminution minime des surfaces vertes (places de jeu, etc.) du fait de l'encombrement causé par les récipients à ordures
Mise à disposition pour la collecte (collecte mixte et séparée)	frais comme déjà mentionnés dans "production de déchets communaux", voir ci-dessus; travail du concierge (rémunération comprise dans le loyer)	frais comme déjà mentionnés dans "production de déchets communaux", voir ci-dessus	comme ci-dessus; altération temporaire de l'esthétique du lieu, du fait de la présence des déchets mis à disposition pour le ramassage
Ramassage et transport	véhicules (frais d'investissement et d'entretien, carburant, amortissement, frais accessoires) personnel (salaires, prestations sociales, etc.) frais divers (garages, locaux pour l'entretien, pour le personnel, etc.) frais de traitement des huiles usées provenant des véhicules de ramassage et de transport.	frais de traitement des déchets provenant de la fabrication des véhicules et de la construction des bâtiments et installations (déchets de production) charge indirecte pour l'environnement, causée par les gaz d'échappement; frais de traitement des déchets résultant de la production du fuel.	encombrement du trafic routier par les véhicules de ramassage et de transport des déchets (en cas d'embouteillages, augmentation des gaz d'échappement) dégradation des bâtiments privés ou publics de valeur historique, des monuments, etc. (pertes éventuelles pour le tourisme), du fait des gaz d'échappement, des vibrations, etc. bruit résultant de l'enlèvement des ordures (violation du calme)
Traitement des déchets (élimination et transformation)			
(a) *décharge non contrôlée*	en général pas de frais	frais ultérieurs pour la liquidation de la décharge et l'assainissement du terrain (sommes considérables)	dégradation et pollution du paysage (pertes pour le tourisme, pertes en surfaces pour les loisirs, l'exploitation agricole ou forestière) dégâts aux arbres résultant des feux qui naissent dans les décharges et peuvent se propager aux alentours pollution des eaux, avec des conséquences parfois très graves pollution des eaux souterraines (répercussions sur l'approvisionnement en eau potable)

(b) *décharge contrôlée* →	frais d'achat ou de location du terrain; frais d'installation (étanchement, drainage, bâtiment de service, etc.); véhicules (investissements et exploitation, carburant, amortissement, frais accessoires); personnel; frais terminaux (réintégration du terrain dans le paysage) frais de traitement des huiles usées provenant des véhicules et machines	frais de traitement des déchets résultant de la production des véhicules, machines, bâtiments et matériaux de construction (déchets de production), charge indirecte pour l'environnement, causée par les gaz d'échappement, frais de traitement des déchets résultant de la production du fuel	sollicitation temporaire de surfaces, pertes temporaires en terrains pour les loisirs ou l'agriculture, encombrement du trafic routier par les véhicules de livraison des déchets à la décharge (en cas d'embouteillages, augmentation des gaz d'échappement)
Compostage →	frais encourus pour les bâtiments et les machines (investissements, entretien, exploitation, amortissement, frais accessoires); achat ou location du terrain; véhicules; personnel; frais pour la mise à la décharge des résidus du compostage	frais de traitement des déchets résultant de la production des véhicules, machines, bâtiments et matériaux de construction (déchets de production), frais de traitement des déchets résultant de la production du fuel, frais de décharge (voir sous décharge contrôlée)	altération de l'aspect du paysage, du fait de la présence des installations et des tas de compost, perte en surfaces pour les loisirs, l'agriculture ou les constructions, émissions et nuisances, encombrement du trafic routier par les véhicules de livraison des déchets et de transport du compost (en cas d'embouteillages, augmentation des gaz d'échappment), charge additionnelle imposée à l'environnement du fait des gaz de combustion
Incinération[1] →	bâtiments, machines et installations (investissements, entretien, amortissement, frais accessoires); achat ou location du terrain; personnel; véhicules frais pour la mise à la décharge des résidus de l'incinération (scories)	frais de traitement des déchets résultant de la production des machines, bâtiments, matériaux de construction, etc. (déchets de production) frais de traitement des déchets résultant de la production du fuel charge indirecte pour l'environnement, causée par les gaz de combustion	altération de l'aspect du paysage, du fait de la présence des installations, etc. perte en surfaces pour les loisirs, l'agriculture ou les constructions, émissions et nuisances, encombrement du trafic routier par les véhicules de livraison des déchets, etc. (en cas d'embouteillages, augmentation des gaz d'échappement) charge additionnelle imposée à l'environnement du fait des gaz de combustion

TABLEAU 1 (*cont.*)

Flux et traitement des déchets	Frais directs	Frais indirects	Pertes en valeurs idéales et culturelles, désavantages économiques
Recyclage[2] →	bâtiments, machines et installations, pour autant qu' ils soient requis pour les opérations de triage et de traitement des déchets en vue de leur utilisation comme matières premières; achat ou location des terrains, véhicules, personnel frais pour la mise à la décharge (ou autres frais de recyclage) des résidus éventuels	suivant les cas, comme pour l'incinération et le compostage, frais pour les études et travaux de recherche concernant la mise au point de nouveaux procédés, frais pour les stations d'essais	suivant les cas, comme pour le compostage et l'incinération
II. DÉCHETS LIQUIDES (eaux usées)			
Production d'eaux usées communales ↓	frais pour les conduites d'eaux usées et le raccordement au réseau de canalisation; frais de construction	frais de traitement des déchets résultant de la production des matériaux requis (déchets de production)	de peu d'importance
Ecoulement des eaux usées communales ↓	frais pour les canalisations (construction, matériaux, entretien et exploitation); véhicules et machines; personnel (nettoyage et entretien des installations);	frais de traitement des déchets résultant de la production des matériaux requis (déchets de production)	altération temporaire de l'esthétique du lieu, du fait des travaux de construction; perturbation du trafic routier du fait de la présence de chantiers et, par conséquent,
Ecoulement . . . (suite) ↓	frais de traitement des déchets solides (matériel défectueux) et des huiles usées provenant des véhicules et machines		bruit causé par les travaux de construction (violation du calme)
Déversement des eaux usées/traitement déversements effectués directement dans des eaux stationnaires ou dans des cours d'eau →	en général pas de frais	grosses dépenses ultérieures pour l'épuration et l'assainissement des eaux polluées (exemple: Lac Erié); frais pour les installations de préparation d'eau potable et frais de	hécatombes de poissons, pertes de gain pour les pêcheurs professionnels, foisonnement d'algues; interdiction des baignades et, par conséquent, grosses pertes pour le

		traitement des déchets résultant de la construction des installations, etc.	tourisme et l'économie nationale (canton du Tessin/Suisse); dégradation et destruction de sites culturels (Venise); altération de la qualité de l'eau potable et d'usage général (maladies, etc.)
décanteurs, stations d'épuration | ⟶	frais pour les installations et machines (investissements, exploitation, entretien); personnel; frais de traitement des boues d'épuration	frais de traitement des déchets résultant de la construction des installations, de la production des matériaux et machines (déchets de production)	nuisances éventuelles pour le voisinage (odeurs fort gênantes dans les quartiers d'habitation); pertes en surfaces pour la construction ou l'agriculture
III. DÉCHETS GAZEUX (gaz produits par: — la circulation routière — les systèmes de chauffage d'immeubles et l'industrie)			
Charges imposées à l'environnement (procédés pour: — la suppression des gaz — la réduction des gaz — l'épuration des gaz)	recherche, développement, essais; installations, appareils et machines (investissements, exploitation et entretien); recherche médicale; perte d'heures-travail; consultations médicales, maladies, médicaments; restauration des bâtiments, monuments, etc.; hausse des amortissements du fait de la durée plus courte des installations; frais pour les pièces de remplacement; hausse des frais d'exploitation	renchérissement des produits, denrées et loyers du fait des installations d'épuration et de réduction des gaz; fermeture d'entreprises, frais sociaux (chômage); hausse des impôts et frais sociaux pour compenser les dépenses accrues de l'Etat; aménagement de nouvelles zones pour les loisirs; augmentation du nombre de lits d'hôpital, frais de formation du personnel hospitalier; hausse des dépenses de l'Etat (protection des monuments, routes de détournement, passages sous-voie, etc.)	atteintes à la santé (disposition accrue de la population aux maladies. apparition de nouvelles maladies, pertes d'heures-travail pour cause de maladie); dégradation et destruction de bâtiments et monuments; effet corrosif sur les ouvrages de construction (abrège leur durée de vie); ce qui nuit aux hommes nuit aussi à la faune et à la flore!

Notice explicative concernant le tableau 1.

(1) En ce qui concerne l'incinération et le calcul des frais d'incinération (voir annexe 2a), il y a lieu de faire la distinction entre trois types d'usine:
— les usines d'incinération sans récupération de la chaleur
— les usines d'incinération avec récupération de la chaleur
— les usines d'incinération avec récupération de la chaleur et traitement des scories.
Non seulement les frais, mais aussi les pertes et les désavantages (dernière colonne), de même que l'intensité et le genre de charge imposée à l'environnement diffèrent selon le type d'usine.

(2) En ce qui concerne le recyclage, il faut en premier lieu déterminer s'il s'agit de
— déchets remis à la collecte mixte et ensuite séparés mécaniquement dans des installations spéciales de recyclage (exemple de Rome), ou de
— déchets collectés séparément par matières (papier, verre, etc.).
Il faut en outre déterminer si
— les matières triées peuvent être réintégrées directement dans le cycle de production industrielle (verre), ou si
— elles doivent d'abord être prétraitées dans l'entreprise même ou dans une autre entreprise (parfois le papier).
Les facteurs "coûts, charge pour l'environnement et le paysage", etc., varient suivant les diverses possibilités et méthodes.

LES FRAIS DIRECTS ET INDIRECTS, LES PERTES ET LES DÉSAVANTAGES CAUSÉS PAR LES DÉCHETS

Abordons alors le thème principal de mon exposé et examinons la question des frais. En prenant connaissance du sujet que l'on m'a demandé de développer devant un aussi illustre auditoire, j'ai d'abord été effrayé. Le traitement approfondi de cette question demande de longues études préalables et il me restait à peine deux mois pour préparer mon exposé—ceci à côté du travail journalier. A défaut de chiffres précis pour les frais indirects, les pertes de valeurs idéales et culturelles et les désavantages économiques, je ne peut procéder que par évaluations. A l'aide de divers tableaux et diagrammes, je vaix essayer de vous montrer toute la complexité des facteurs qui entrent dans la composition des frais résultant des déchets depuis leur production jusqu'à leur traitement.

Comme la Ligue pour la Propreté en Suisse, dont je suis le secrétaire général, s'occupe principalement des problèmes relatifs aux déchets solides, je me permets de commencer par ces déchets-là, quoique les premières figures (voir annexe 1) montrent clairement qu'ils imposent à l'environnement des charges bien moins accablantes que les déchets liquides et gazeux.

Déchets solides collectés par les services communaux (en chiffres). Les frais directs causés par les déchets solides se montent en Suisse (6,3 millions d'hab.) à environ 360 millions de francs suisses par an (production annuelle de déchets communaux en Suisse: 1,6 million de tonnes environ).

Production totale de déchets solides (y compris les déchets non communaux et les boues d'épuration). La production totale est approximativement de 3,8 millions de tonnes par an et les *frais directs* se montent à environ 500–550 millions de francs, y compris les frais pour

les récipients et sacs à ordures, la mise à disposition, le ramassage, le transport et le traitement.

Les *frais indirects* et, en particulier, les *frais sociaux* (social costs), les *pertes* en valeurs idéales et culturelles, les *désavantages économiques* (tourisme) ne peuvent guère être exprimés en chiffres; il faudrait pour cela des années d'étude et de recherche.

Les *frais de construction* d'usines communales et régionales de traitement des déchets (donc non compris les installations appartenant à des entreprises industrielles) se montaient à fin 1970 à:

approx.	310 mio.Fr.	pour	37 usines en service
„	140 „	„	15 usines en construction
„	150 „	„	12 usines encore à l'état de projet

Déchets liquides (*eaux usées*), en chiffres. Les frais directs causés par les eaux usées se montent en Suisse à environ 700 millions de francs (production annuelle d'eaux usées: environ 2,500 millions de tonnes).

Les frais indirects et les frais sociaux (social costs) sont à peu près les mêmes que pour les déchets solides.

Les frais de construction de stations communales et régionales d'épuration des eaux usées (donc non compris les stations d'épuration appartenant à des entreprises industrielles) se montaient, à fin 1970, à:

approx.	760 mio.Fr.	pour	366 stations en service
„	420 „	„	89 stations en construction
„	260 „	„	103 stations encore à l'état de projet
„	350 „	„	43 stations prévues

Remarque. Les chiffres indiqués ne comprennent qu'une partie des frais d'élimination des déchets, c'est-à-dire la partie qui est à la charge des services communaux. Les frais totaux qui incombent aux ménages, administrations, métiers, industries, communications et transports, au commerce, à l'agriculture, à la sylviculture et au tourisme, pour la protection de l'environnement, se chiffrent approximativement à 2–5 % du produit national brut (en 1970, env. 2–4 milliards de francs suisses), pour autant naturellement que toutes les mesures nécessaires aient été prises.

Evaluation en du produit national brut:
(situation en 1972)

canalisations et stations d'épuration	1,0
usines de traitement des déchets (y compris les décharges)	0,2
autres installations de protection de l'environnement, du secteur public	0,1
mesures de protection de l'environnement, entreprises par les institutions officielles, l'industrie, le commerce et les particuliers	1,2
	2,5

Le produit national brut étant de 86 milliards de francs suisses, les investissements globaux pour la protection de l'environnement se montaient à plus de 2 milliards.

Le tableau 2 donne un aperçu des frais effectifs créés au cours du flux des déchets solides (de leur production à leur traitement) et suggère en même temps les mesures susceptibles de réduire les quantités de déchets et, par conséquent, de réduire également les frais.

TABLEAU 2. Frais directs moyens (approximatifs), causés par les déchets solides (en Suisse, 1973)

	Frais en 1974	Frais prévisionnels	Possibilités de réduire les frais
— *Production de déchets communaux* (ménages, commerce, etc.) en moyenne 260 kg par habitant et par an Frais pour récipients, Frais d'encombrement	Fr. 120.—/t (192 mio/Suisse)*	renchérissement de 10% ou plus par an, augmentation des frais dû à l'accroissement de la production de déchets	emploi accru d'emballages de circulation, production de marchandises plus durables utilisation de quantités moindres de matières premières par produit, si cela n'influence pas la durabilité des marchandises
— *Mise à disposition des déchets pour la collecte*	(généralement compris dans les chiffres ci-dessus)		
— *Collecte des déchets*			
(a) collecte globale (mixte)	Fr. 50.—/t (80 mio/Suisse)	renchérissement de 10% ou plus par an, (frais de personnel et de carburant)	en général pas de possibilités[1]
(b) collecte séparée du papier	Fr. 90.—/t (63 mio/Suisse)**	renchérissement de 10% ou plus par an, (frais de personnel et de carburant)	ces frais sont en général fictifs, puisqu'ils sont couverts par les recettes de la vente du papier (actuellement Fr. 120/240.—/t)
(c) collecte séparée du verre	Fr. 140.—/t (18 mio/Suisse)**	renchérissement de 10% ou plus par an, (frais de personnel et de carburant)	ces frais existent partiellement, mais ils ne devraient en réalité pas exister; il faudra pouvoir les compenser par des ristournes plus élevées consenties par les verreries
— *Traitement des déchets*			
(a) décharges non contrôlées	pas de frais directs en général	somme de plusieurs millions de francs consacré à la réparation des dégâts infligés au paysage et aux eaux	cessation immédiate de l'exploitation de décharges non contrôlées (ces décharges sont interdites par la loi fédérale de protection des eaux—1.7.1972) assainissement, aussi rapidement que possible
(b) décharges contrôlées	Fr. 20.—/t (32 mio/Suisse)**	renchérissement de 10% ou plus par an, (frais de personnel, de carburant et d'exploitation)	réduction générale de la production de déchets (voir sous production ci-dessus) recyclage accru (collectes séparées,

			traitement des scories, etc.) installation de grandes décharges (réduction des frais financiers et d'exploitation par tonne)
(c) compostage	Fr. 45.—/t (72 mio/Suisse)**	renchérissement . . . (voir ci-dessus) hausse des frais d'entretien et d'agrandissement	meilleurs compensation des frais par le produit de la vente du compost (exploitation de nouveaux marchés) installation dc grandes usines de compostage (réduction des frais financiers ct d'cxploitation par tonne)
(d) incinération (considérée généralement)	Fr. 60.—/t (96 mio/Suisse)**	renchérissement de 10% ou plus par an, (frais de personnel, et d'exploitation cn général) haussc des frais d'entretien et d'agrandissement	réduction générale de la production de déchets (voir sous production ci-dessus) recyclage accru installation de grandes usines rationnelles avec récupération de la chaleur (énergie) et traitement des scories (réduction des frais financiers et d'exploitation par tonne; augmentation des recettes
incinération sans récupération de la chaleur	Fr. 75/95.—/t	renchérissement de 10% ou plus par an, (frais de personnel, d'énergie et d'exploitation en général) hausse des frais d'entretien et d'agrandissement	il est préférable de cesser de construire ou d'agrandir ce genre d'usines d'incinération (charge accrue pour l'environnement; manque de recettes)
incinération avec récupération de la chaleur	Fr. 45/60.—/t	renchérissement . . . (voir ci-dessus) hausse des frais . . . (voir ci-dessus)	installation de grandes usines permettant une exploitation rationnelle (réduction des frais financiers et d'exploitation par tonne), compensation accrue des frais par le produit de la vente de l'énergie et de la chaleur, diminution des charges imposées à l'environnement
incinération avec récupération de la chaleur et récupération des scories (une installation en service depuis quelques mois)	Fr. ??????	renchérissement . . . (voir ci-dessus) hausse des frais . . . (voir ci-dessus)	installation de grandes usines . . . (voir ci-dessus) en plus: suppression des frais de décharge pour les scories,

TABLEAU 2 (*cont.*)

	Frais en 1974	Frais prévisionnels	Possibilités de reduire les frais
			compensation accrue des frais par le produit de la vente des scories comme matériau de construction de routes
(e) *recyclage* recyclage par collectes séparées — pour le papier	Fr. 90.—/t pour le ramassage Fr. 120.—/t ev. pour le triage	renchérissement de 10% ou plus par an, (frais de personnel, de carburant et d'exploitation) hausse des frais pour les installations et l'entretien	ces frais sont en général fictifs, puisqu'ils sont couverts par les recettes de la vente du papier
— pour le verre	Fr. 140.—/t pour le ramassage	renchérissement . . . (voir ci-dessus)	ces frais existent partiellement, mais ils ne devraient pas exister; comme pour le papier, ils doivent être couverts par les recettes de la vente du verre
recyclage global (à l'exemple des grandes usines de recyclage de la ville de Rome)(2)	env. Fr. 35.—/t (situation 1973)	renchérissement de 10% ou plus par an, (frais de personnel et d'exploitation) hausse des frais pour les installations et l'entretien	une fois toutes les étapes de recyclage en service, les frais sont en large mesure compensés par le produit de la vente des diverses matières premières

Explications:
* (. . mio/Suisse)=frais en millions de francs suisses.
** (. . mio/Suisse)=frais en millions de francs suisses, si la quantité totale des déchets communaux était traitée selon la méthode en question.

Notice explicative concernant le tableau 2:

(1) Les économies pouvant éventuellement être réalisées dépendent du mode de collecte

— frais de collecte calculés per capita:
dans ce cas, la collecte séparée (papier, verre, etc.) n'apporte pas de réduction des frais du ramassage global;

— frais de collecte calculés par tonne:
dans ce cas, la collecte séparée peut apporter une réduction des frais du ramassage global, réduction qui n'est que fictive, puisque, tôt ou tard, on sera obligé d'augmenter les frais du ramassage global.

Le parcours de collecte, ainsi que les frais d'exploitation (véhicules, personnel, etc.) pour le ramassage global restent inchangés; ainsi, les frais se répartissent sur un tonnage inférieur.

(2) Voir annexe 3.

On pourrait citer et analyser d'innombrables exemples, mais le temps manque pour cela dans le cadre de cet exposé. J'espère toutefois avoir réussi à mettre en évidence la complexité du problème et la multitude des facteurs qui entrent dans la composition des frais.

Tournons maintenant un regard vers l'avenir.

QUE NOUS RÉSERVE L'AVENIR?

Les perspectives d'avenir ne sont guère réjouissantes, comme semble le prouver une étude des frais effectuée par le Comité de l'environnement de l'OCDE et son Sous-Comité d'Experts Economiques.

Les estimations publiées diffèrent considérablement; elles s'échelonnent de 1 à 10 % du produit national brut.

Suisse

Pour la Suisse, les coûts de la lutte contre la pollution sont connus pour le secteur public seulement. Les autorités publiques ont dépensé en 1969 450 millions de francs suisses pour combattre la pollution. Ce chiffre représente près de 0,6 % du PNB. Environ 350 millions de francs ont été affectés à la lutte contre la pollution de l'eau et 100 millions à la lutte contre la pollution de l'air et à l'élimination des déchets solides. Les frais d'exploitation (amortissement non compris) s'élevaient à un tiers environ de la dépense totale, soit environ 2 % des dépenses courantes du secteur public; la dépense d'investissement s'élevait à 10 % environ des investissements publics et à 1,5 % de la formation totale de capital fixe dans l'économie du pays.

Allemagne

Les renseignements ci-après sont extraits des estimations de coûts qui ont été établies au printemps 1971 pour la préparation du programme allemand relatif à l'environnement.

Pour les nouveaux besoins du programme de la politique de l'environnement, une somme de l'ordre de 28 milliards de DM devra être investie, et près de 8 milliards de DM seront dépensés au titre des frais d'exploitation entre 1971 et 75. Le total, soit 36 milliards de DM,

représentera 1 % environ du PNB. En outre un montant supplémentaire de 34,5 milliards sera consacré à la poursuite des activités anti-pollution déjà engagées avant 1971. Ces dernières comprennent:

Frais d'exploitation	DM 25 milliards
Investissements pour renouvellement des installations	DM 6,5 milliards
Autres dépenses (frais de recherche)	DM 3 milliards

Au total les dépenses pour la période 1971–5 atteindront près de 70,5 milliards de DM, ce qui équivaudra à 1,8 % environ du PNB (voir Tableau 3).

L'investissement net en installations de lutte contre la pollution était de 2,7 milliards de DM en 1970. Les frais correspondants d'exploitation, de remplacement et de recherche étaient de 6,9 milliards, ce qui fait un total de 9,6 milliards de DM en 1970. Si l'on ajoutait les frais d'exploitation, etc., des installations anti-pollution d'avant 1970 à l'estimation de la dépense de lutte contre la pollution pour 1975, ceci donnerait une dépense totale de 17,7 milliards de DM. Par rapport aux PNB correspondants, ces chiffres reflètent une augmentation dans la part du PNB qui passe de 1,4 % en 1970 à 2,1 % en 1975.

Tableau 3. Les coûts du programme 1971–5 (chiffres en milliards de DM)

	Investissements		Frais d'exploitation		Total	
	DM	%	DM	%	DM	%
Pollution de l'air	3,9	14	0,4	5	4,3	12
Pollution de l'eau	16,2	58	4,0	50	20,2	56
Déchets solides	2,2	8	1,5	19	3,7	10
Biocides et prod. chim. contenus dans l'environnement	1,4	5	—	—	1,4	4
Nuisances dues au bruit	1,7	6	—	—	1,7	5
Protection de la nature, considérations esthétiques	2,4	9	—	—	2,4	7
Non spécifié (évaluation globale)	0,2	0	2,1	26	2,3	6
Total	28,0	100	8,0	100	36,0	100

Etats-Unis

Les chiffres suivants sont tirés de "Environmental Quality"—troisième rapport annuel du "Council of Environmental Quality".

Les investissements annuels à prévoir pour la lutte contre la pollution passeront de 3,6 milliards de S en 1970 à 9,5 milliards de S en 1980, tandis que le capital investi dans les

Tableau 4. Les investissements en capital en milliards de S

	1970 Installations	Annuel	1980 Installations	Annuel	en %
Pollution de l'air	1,5	1,0	29,8	6,0	63,2
Pollution de l'eau	23,3	2,5	46,0	3,0	31,5
Déchets solides	N.D.	0,1	N.D.	0,3	3,2
Autres (bruit, etc.)	—	—	1,2	0,2	2,1
Total	24,8	3,6	77,0	9,5	100

installations qui était évalué en 1970 à 24,8 milliards atteindra en 1980 77 milliards de \$. D'après une enquête effectuée, les entreprises américaines devront investir 22,8 milliards de \$ pour aligner toutes leurs installations sur les normes de pollution de l'air et de l'eau en vigueur depuis le 1er janvier 1972.

Le tableau 5 donne la répartition annuelle des coûts afférents aux types de pollution mentionnés pour 1970 et 1980. Au total, pour les Etats-Unis, les coûts annuels (frais d'exploitation augmentés de l'intérêt du capital investi et de l'amortissement des installations existantes) passeront de 10,4 milliards de \$ en 1970 à 33,3 milliards en 1980, soit une augmentation de 220 %. Les dépenses correspondantes par habitant atteindront 145 dollars en 1980 contre 51 dollars en 1970.

TABLEAU 5. Répartition annuelle des coûts (en milliards de \$—1971)

	1970	%	1980	%
Pollution de l'air	0,8	7,7	14,7	44,1
Pollution de l'eau	3,6	34,6	8,0	24,0
Déchets solides	6,0	57,7	9,7	29,1
Autres (bruit, rayonnements, reconstruction des sols)	0	0	0,9	2,8
Total	10,4	100	33,3	100

Le total des dépenses qui seront effectivement exposées s'élévera au cours de la période 1971–80 à 287,1 milliards de \$, exprimées en % ces dépenses se répartissent comme suit: Air=37 %, Eau=30 %, Déchets solides=30 % et Autres=3 %.

Le tableau 6 ci-dessous donne une récapitulation des besoins cumulés pour l'ensemble de la décennie (1971–80).

TABLEAU 6. Besoins cumulés 1971–80 (en milliards de \$—1971)

	Investissement en capital	Coûts d'exploitation	Bénéfice avant amortissement
Pollution de l'air	48,2	58,3	106,5
Pollution de l'eau	40,2	47,1	87,3
Déchets solides	3,0	83,1	86,1
Autres (bruit, etc.)	1,4	5,8	7,2
Total	92,8	194,3	287,1

Le montant total de 287,1 milliards de \$, représentera 2,2 % du PNB pour la période 1971–80, contre 1,6 % indiqué pour la période 1970–6.

Une étude qui porte sur l'incidence des mesures actuellement requises pour lutter contre la pollution de l'air et de l'eau sur quatorze activités industrielles et sur l'économie dans son ensemble a été réalisée aux Etats-Unis. L'incidence macro-économique de ces mesures a été résumée comme suit:

"Il résulte de l'étude que l'économie du pays ne sera pas gravement obérée par l'institution de normes de réduction de la pollution. Elle n'en subira pas moins des incidencees non négligeables."

On peut citer à cet égard les estimations suivantes:

"La lutte contre la pollution ralentira de 0,3 % au cours de la période 1972–6 et de 0,1 % au cours de la présente décennie la cadence de croissance annuelle moyenne du PNB. Entre 1972 et 1976, son incidence sera chaque année d'environ 0,5 % sur les coûts des investissements fixes et de 0,2 % sur l'indice des prix à la consommation. Pendant la période 1972–80 le chômage augmentera d'environ 1,1 % et on constatera en 1980 que le déficit de la balance des paiements aura augmenté de 0,7 milliard de $ par an."

Pour la période 1972–80, l'effet des coûts de la lutte contre la pollution sur l'indice des prix à la consommation devrait être de l'ordre de 0,25 % par an. Dans ce cas, l'effet sur la balance des paiements se chiffrerait à environ 2 milliards de dollars par an. Toutefois, cette estimation aux Etats-Unis ne tient pas compte du fait que la lutte contre la pollution alourdit également les coûts de production des autres pays.

En ce qui concerne l'incidence micro-économique, l'étude révèle qu'aucune des industries qui ont été examinées ne serait gravement touchée, car les coûts estimés de la lutte contre la pollution ne sont pas les seuls facteurs qui menacent sérieusement la viabilité à long terme de tel ou tel secteur. Parmi les 12 000 usines des industries examinées, on s'attend à ce que 800 ferment leurs portes du fait de l'évolution normale des affaires entre 1972 et 1976. On estime à près de 200 à 300 le nombre des usines qui seront obligées de mettre fin à leur activité en raison des conditions édictées pour la lutte contre la pollution.

D'un côté, nous allons être obligés de dépenser des sommes encore plus grandes pour rattraper le retard; de l'autre, les quantités sans cesse croissantes de déchets vont causer d'énormes frais supplémentaires; il va de soi que chaque citoyen devra en supporter sa part.

Selon une étude allemande sur les frais de protection de l'environnement causés par la circulation routière, il faudrait dépenser DM 3500 par habitant et DM 1600 par automobile pour ramener à une mesure tolérable le bruit et les gaz d'échappement émis par les autos. Il s'agirait de mesures "passives" (par exemple fenêtres spéciales) et de mesures "actives" (modifications apportées aux voitures pour réduire les émissions de bruit et de gaz d'échappement). La République fédérale d'Allemagne devrait dépenser, uniquement pour les mesures de réduction des gaz d'échappement, 18,8 milliards de DM entre 1973 et 1982.

La question suivante se pose: quelle est la charge que l'environnement urbain doit supporter du fait du bruit et des gaz d'échappement émis par les automobiles?

Pour y répondre, il faut commencer par déterminer les effets psychologiques et physiologiques que le bruit et les gaz d'échappement ont sur les êtres humains, c'est-à-dire dans quelle mesure ils portent atteinte à la santé et à la capacité de travail des hommes. Il faut aussi essayer de déterminer à combien se montent les frais qui en découlent pour l'économie nationale (par exemple pour le traitement médical). Si le niveau actuel de la science ne permet pas cette quantification, on peut tourner la question comme suit: combien cela coûterait-il à l'économie nationale de réduire cette charge à une mesure indiquée par les milieux médicaux, de façon à éviter toute atteinte à la santé publique?

En ce qui concerne le bruit produit par la circulation routière, on constate qu'il exerce sur les hommes les effets nocifs suivants: difficultés de communication, baisse de la capacité de travail, perturbations de la santé de ceux dont les activités se déroulent à l'extérieur (travaux, emplettes, etc.). Les effets du bruit sont pires encore pour ceux qui travaillent dans

des immeubles ou habitent dans des maisons se trouvant en bordure de rues à forte circulation automobile.

Comme il n'a pas été possible jusqu'à présent de prouver qu'il existe des maladies spécifiquement dues au bruit, il est très difficile ou même impossible de déterminer les frais pour les malaises ou troubles de santé qui en résultent. Il est encore plus difficile d'évaluer les effets cumulés du bruit, des gaz d'échappement et des autres facteurs de stress. A ce sujet, il y aurait lieu par exemple de déterminer la valeur que chaque individu attribue au repos nocturne.

Les frais des mesures palliatives sont les frais pour les modifications apportées aux automobiles (mesures actives) et les frais pour les modifications dans la construction d'immeubles et de routes—mesures d'insonorisation par exemple (mesures passives).

Les frais pour les mesures d'insonorisation appliquées aux immeubles se montent à 1,7–4,8 millions de DM par km de rue. Pour Cologne par exemple, ville qui compte 924 000 habitants, ces frais atteindraient 3,23 milliards de DM ou 3500 DM par habitant. En calculant ces frais en fonction des automobiles qui circulent dans la ville, chaque voiture faisant en moyenne 5000 km par an, on arrive à 4 Pfennig par km de course.

Le problème se complique lorsqu'on prend aussi en considération la pollution de l'air due à la circulation automobile. La composition des gaz d'échappement dépend de toute une série de caractéristiques du fonctionnement des automobiles: marche du moteur, mélange, cylindrée, taux de compression, etc. D'autres facteurs sont l'âge de la voiture, son état, etc. Il y a également des facteurs spécifiques de la circulation: intensité du trafic, cycles (temps de stationnement, d'accélération et de décélération), qui, eux aussi, influent sur la quantité et la composition des gaz d'échappement.

La répartition des composants polluants dépend aussi de la largeur des rues, de la hauteur des bâtiments et varie avec les conditions météorologiques.

On voit donc qu'il n'existe pratiquement pas d'indicateurs pour l'évaluation de la charge actuelle de l'atmosphère en gaz d'échappement.

On considère principalement comme nuisances les effets que le bruit exerce sur les hommes, mais on ne peut pas nier aujourd'hui que les gaz d'échappement des automobiles nuisent à la santé humaine.

Il est toutefois presque impossible d'évaluer les effets chroniques que les substances polluantes que nous respirons année après année ont sur notre organisme. Les effets immédiats ne sont sans doute pas très graves, mais peuvent fort bien causer à la longue de sérieux troubles de santé, amoindrir nos capacités ou, tout simplement, nous mettre en mauvais état physique.

Comme dans le cas du bruit, les perturbations causées par les gaz d'échappement sont difficiles à déterminer avec certitude et à évaluer en tant que frais. Il faudrait pour cela que la recherche médicale s'occupe de déterminer les atteintes à la santé, la réduction de la durée de vie et du bien-être des hommes, attribuables aux gaz d'échappement. Il faudrait en même temps posséder un critère d'évaluation pour traduire en frais les préjudices en question. Pour le moment, c'est encore chose impossible.

Cette lacune dans l'information nous oblige à évaluer les dépenses spécifiquement requises pour l'observance des valeurs-limites imposées par la médecine dans l'intérêt de la santé publique.

La solution la moins coûteuse et la plus avantageuse du point de vue de l'environnement consisterait à limiter rigoureusement la production de déchets; ce serait, pour ainsi dire, le

retour à l'âge des cavernes, époque où il n'y avait que des déchets organiques qui étaient sans autre réintégrés dans le cycle de la nature. Mais ne nous attardons pas sur des pensées utopiques et revenons à la réalité!

Il est indispensable d'arriver à

— réduire, par des mesures appropriées, la production de déchets;
— réduire autant que possible, par une bonne gestion des déchets, les charges imposées à l'environnement;
— retarder autant que possible, par un recyclage rationnel, l'épuisement des ressources naturelles;
— maintenir les frais dans des limites économiquement tolérables, grâce à l'optimisation et la rationalisation.

(a) *Réduction de la production de déchets*

Il faut absolument

— faire perdre aux consommateurs leurs habitudes de gaspillage (emballages perdus et marchandises de courte durée) et les inciter à devenir plus économes—le renchérissement et l'inflation seront probablement bénéfiques à ce point de vue;
— obtenir des fabricants qu'ils produisent des marchandises et denrées plus durables—du point de vue de la technique, c'est parfaitement réalisable, mais il n'est pas sûr que ce le soit aussi du point de vue de l'économie des entreprises. Le mot d'ordre d'avenir de l'industrie devra être: "Qualité et durabilité au lieu de quantité et vie courte."

La recherche et la technique doivent arriver à

— réduire la consommation de matières premières et, partant, les quantités de matières entrant dans la fabrication de chaque produit, pour autant que cela ne diminue pas la durabilité du produit. Il en est de même pour ce qui est de la consommation d'énergie: en économisant l'énergie on produit moins de déchets.

L'industrie et le commerce doivent accepter de

— contribuer à réduire la production de déchets en utilisant plus d'emballages de circulation, de transport et de vente (cela concerne principalement le secteur des biens de consommation de masse).

En plus d'une réduction effective des quantités de déchets—il ne s'agit en l'occurrence que des déchets solides, à l'exclusion des eaux usées et des gaz d'échappement, de combustion, etc.—les mesures précitées doivent contribuer à réduire les frais directs et indirects, ainsi que les pertes et les désavantages.

(b) *Réduction des charges imposées à l'environnement*

Comme ce sont les charges imposées à l'environnement et les dégâts que nous lui infligeons qui occasionneront à l'avenir les frais les plus élevés, les pertes les plus graves en valeurs idéales et culturelles et les désavantages économiques les plus sérieux, il est indiscutable qu'une bonne gestion des déchets est une mesure capitale de réduction des frais.

C'est surtout dans un pays fédéraliste comme la Suisse, avec ses 25 cantons et plus de 3000 communes, que

— les solutions communales, de peu d'envergure, doivent céder le pas aux solutions

globales, à l'échelon régional ou suprarégional. Les intérêts locaux doivent rester à l'arrière-plan pour que l'on ait:

— au lieu d'une quantité de petites usines de traitement des déchets, petites usines qui travaillent à frais élevés et polluent outre mesure l'environnement (gaz de combustion, etc.),
  de grandes usines rationnelles qui travaillent à moins de frais (par tonne) et qui soient munies des installations les plus modernes et perfectionnées pour la protection de l'environnement (réduction des charges imposées à l'environnement).

Les deux exemples donnés dans les annexes 2c et 2d prouvent clairement que les frais par tonne diminuent sensiblement plus on augmente la capacité de l'usine de traitement (voir annexes 2c et 2d).

On arrivera mieux à réduire la charge imposée à l'environnement et les frais en construisant et exploitant quelques grandes usines de traitement des déchets plutôt que beaucoup d'usines de petite et moyenne capacité. Cela s'applique non seulement aux installations conventionnelles (usines d'incinération et de compostage, décharges contrôlées, etc.), mais aussi et surtout aux usines de recyclage.

Au lieu de la soixantaine d'installations déjà en service ou encore en construction, il suffira à l'avenir d'avoir au maximum 23 installations de grande capacité (usines de recyclage combinées avec des installations d'incinération, de compostage, de traitement des scories et une décharge contrôlée) pour traiter et recycler rationnellement tous les déchets communaux (1,6 million de tonnes par an).

Il est également essentiel de déterminer le système de gestion des déchets qui convient le mieux, premièrement du point de vue de la réduction des charges imposées à l'environnement, et secondement du point de vue de la réduction des frais (optimisation de la technique de gestion des déchets—voir annexe 2e).

(c) *Recyclage rationnel, dans l'intérêt de la conservation des ressources naturelles*

On ne peut désormais plus concevoir que la protection de l'environnement reste limitée à l'échelon national. Pour la Suisse par exemple—pays extrêmement pauvre en matières premières—le recyclage n'apporte quasiment pas de réduction directe des charges imposées à l'environnement du fait de l'exploitation des ressources naturelles.

Toutefois, le recyclage apporte

— une réduction directe des charges imposées à l'environnement du fait du traitement des déchets et, par conséquent, une sensible réduction des frais;
— une plus grande indépendance vis-à-vis de l'étranger en ce qui concerne certaines matières premières, ce qui est un avantage pour l'économie nationale.

Comme toutes les mesures de réduction des frais ne pourront guère être réalisées à court terme, ou même à moyen terme, nous sommes d'avis que les frais causés par les déchets, frais qui font actuellement 1,5–2,1 % du produit national brut, feront à l'avenir les 4–5 % du produit national brut. Cela représente une charge énorme pour la nation, et chaque citoyen s'en ressentira.

La discussion des frais causés par les déchets risque de nous amener à conclure que la solution aux problèmes de l'environnement, c'est-à-dire de la dégradation de notre milieu vital, nous sera fournie par le progrès technologique. Bien des gens croient que si la technique a créé des problèmes pour l'environnement, une nouvelle technologie sera capable

de les résoudre; ils croient aussi qu'on pourra acheter la guérison de notre monde malade en payant les frais de cette technologie.

Ernest Basler, renommé pour ses études sur les problèmes de l'environnement, a exprimé dans la formule suivante les facteurs essentiels qui déterminent la charge imposée à notre milieu vital:

$$Q = \frac{B \cdot k}{R \cdot n} = \frac{\text{population} \times \text{consommation per capita}}{\text{milieu vital} \times \text{degré d'efficacité écologique}}$$

(voir annexe 2f).

La charge (Q) imposée à l'espace vital croît avec le nombre d'habitants (B) et la consommation moyenne per capita (k). D'autre part, cette charge se répartit sur l'espace vital à disposition (R), espace qui ne peut pas être agrandi et qui est la seule grandeur fixe dans cette formule. Le degré d'efficacité écologique (n) indique l'effet qu'un taux déterminé de consommation exerce sur l'écologie. Les moteurs automobiles actuels produisent un volume déterminé de transport, dont la valeur écologique est plus petite que celle des moteurs non polluants. Le degré d'efficacité (n) est par conséquent déterminé par l'état auquel est parvenue la technologie de l'environnement. La consommation par tête d'habitant (k) s'exprime par des grandeurs telles que, par exemple, la surface habitée par personne (y compris la résidence secondaire ou la maison de vacances), le nombre annuel de kilomètres parcourus en auto, la consommation annuelle d'énergie en kWh par personne, etc. Dans un système où la technologie de l'environnement existe déjà, la consommation per capita est à peu près proportionnelle au revenu per capita.

Mécanismes de l'accroissement en fonction de ces facteurs: (R) reste constant, tandis que la population et la consommation per capita augmentent, et cela, pour une part essentielle, de façon exponentielle. Cela doit forcément amener une collision avec les plafonds de crise et avec les limites écologiques.

On arrive ainsi à la question de savoir comment la technologie—en particulier la technologie de l'environnement—peut nous aider à éviter la collision. Elle détermine le degré d'efficacité écologique (n) qui indique dans quelle mesure un niveau déterminé de consommation accable l'environnement. On peut citer en exemple l'épuration des eaux usées ou la mise au point d'automobiles sans échappements de gaz nocifs. Une voiture qui ne dégage plus qu'un tiers de gaz par kilomètre a une valeur écologique plus élevée. Une machine—par exemple une auto—qui s'use moins rapidement et dont la vie est par conséquent plus longue (qui nécessite donc des amortissements moins élevés) possède un meilleur degré d'efficacité écologique pour ce qui est de la consommation de matières premières, etc. A consommation égale, la charge imposée à l'environnement est moins grande, ou, dit de façon plus osée, à charge égale imposée à l'environnement correspond une consommation qui peut de nouveau être accrue. Nous voici ainsi arrivés au piège technologique et à l'insuffisance de la stratégie!

Faisons la supposition suivante: en 1960, aucune mesure de réduction des gaz d'échappement n'est encore appliquée; en considération de l'accroissement des kilomètres annuels parcourus par les automobiles, accroissement qui est de 7 %, la limite de tolérance sera atteinte en 1980 déjà. On met alors au point un moteur qui permet d'éliminer les 80 % des gaz d'échappement. Admettons que ce nouveau moteur soit mis sur le marché dès 1970 et que, jusqu'en 1980, toutes les voitures en soient munies. Le succès est certain, se dira-t-on

en 1980—la pollution de l'air est bien inférieure à ce qu'elle était il y a dix ans. En réalité, la situation se remettra à empirer dès 1980 et la collision avec la limite de tolérance—retardée d'une vingtaine d'années—finira tout de même par avoir lieu, pour la simple raison que l'on n'aura pas résolu le problème fondamental, c'est-à-dire celui de l'accroissement.

Le même processus se déroule en Suisse, dans le domaine de la protection des eaux, comme l'a dit le Professeur Wuhrmann dans une de ses conférences. Nous construisons des stations d'épuration depuis une vingtaine d'années et espérons que, d'ici quelques années, nous serons en mesure d'épurer la totalité des eaux usées produites dans notre pays. On constate déjà une amélioration de la qualité de l'eau de diverses rivières et de plusieurs lacs. Si cependant la tendance actuelle se poursuit, c'est-à-dire si nous continuons de produire chaque année 3–6 % plus d'eaux usées—même si elles sont épurées—il faut s'attendre à ce que la pollution des eaux soit dans une dizaine d'années, malgré toutes les stations d'épuration, de nouveau aussi grande que vingt ans auparavant, avant la construction des nouvelles stations d'épuration.

La protection technologique de l'environnement est incapable, *à elle seule*, de résoudre le problème.

Quant à savoir dans quelle mesure on pourra, grâce à d'énormes investissements, éviter ou retarder (pour combien de temps?) la crise de l'environnement, je n'ai pas la prétention de répondre à cette question. Je préfère laisser les futurologues débattre ce problème. A mon humble avis, il faudra non seulement de l'argent—beaucoup d'argent—mais aussi une modification fondamentale de la structure sociale, de notre mentalité et de notre manière d'agir, si nous voulons nous conformer à l'idée directrice de ce congrès mondial qui s'intitule "Vers un plan d'action pour l'humanité".

Je vous remercie de l'attention que vous m'avez accordée.

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Les tableaux ont été préparés spécialement pour cette occasion par l'auteur de l'exposé.

ANNEXE 1

TABLEAU 7. Gaz d'échappement à la sortie des cheminées

No.	Consommation en mio.de t. par an	Nature des gaz d'échappement	Substances polluantes offensives mio.t/an	Substances polluantes inof. mio.t/an	Agt. de transport: air mio.t./an
	8	*mazout et huile Diesel* C=89%			
		H=10%, S=1%			140
		H_2O+CO_2	21		
		SO_2		0,2	
2	2	*benzine* C=89%, H=10%			
		plomb, etc., 1%			25
		H_2O+CO_2	5		
		combinaisons organiques PbO, NO_2, CO et autres combinaisons inorganiques		0,2	
	4	*ciment*			
		(les combustibles du No 1 contiennent du H_2O et du CO_2 provenant du Ca CO_3)	1		
		poudre de clinker		0,1	
4	3	*gaz d'échappement du reste de l'industrie et des métiers, ainsi que ceux produits par l'incinération des gadoues et des boues*			535
		(les gaz produits par la combustion du mazout—voir No. 1—contiennent du CO_2 et du H_2O)	2		
		substances polluantes		0,2	
5		émissions dans l'atmosphère	29	0,7	700
6		total des gaz	730		
7		concentration moyenne des substances polluantes contenues dans les gaz	100 g/t d'air		

TABLEAU 8. Eaux usées avant l'entrée dans les stations d'épuration

No.	Production mio t/an	Nature des eaux usées	Substances polluantes inoffens. mio. t/an	Substances polluantes nocives mio. t/an	Agt. de transport: eau mio. t/an
8	1000	*eaux usées communales*			1000
		sels inorganiques, sans les substances nutritives	0,1		
		matières décomposables, sous forme de C		0,07	
		matières non-décomposables, sous forme de C		0,03	
		substances nutritives (fertilisants), sous forme de P		0,01	
		pollution mécanique		0,02	
9	1000	*eaux usées ne provenant pas des communes*			1000
		sels organiques, sans les substances nutritives	0,1		

TABLEAU 8. (*cont.*)

No.	Nature	inoffens.	nocives	
	matières décomposables, sous forme de C		0,07	
	matières non-décomposables, sous forme de C		0,03	
	substances nutritives (fertilisants), sous forme de P		0,01	
	pollution mécanique		0,01	
10	émissions dans l'eau	0,2	0,26	2000
11	total des eaux usées		2000	
12	concentration moyenne des substances polluantes contenues dans les eaux usées		130 g/t	

TABLEAU 9. Déchets solides avant l'incinération

No.	Production mio. t/an	Nature des déchets	Substances polluantes inoffens. mio. t/an	nocives	moyen de transport: camions mio. t/an
13	1,2	*déchets traités dans les installations communales*			
		inoffensifs	1,2		4
		soufre et déchets halogénés		0,01	
14	0,8	*autres déchets*			3
		inoffensifs	0,8		
		substances nocives		0,01	
15	1,0	*boues produites par les stations d'épuration*	1,0	0,01	3
16	3,0	déchets solides	3,0	0,03	10
17		poids brut au transport		13	
18		charge utile: poids brut		23%	

TABLEAU 10. Bilan total des substances polluantes

No.		Substances polluantes inoffens. mio. t/an	nocives	Total en mio. t/an
5	dans les gaz d'échappement	29,0	0,7	29,7
10	dans les eaux usées	0,2	0,26	0,46
16	dans les déchets solides	3,0	0,03	3,03
		32,2	1,0	33,2
—	*les gaz d'échappement contiennent:*			
	— substances polluantes au total			89,5%
	— substances nocives		71%	
—	*les eaux usées contiennent:*			
	— substances polluantes au total			1,5%
	— substances nocives		26%	
—	*les déchets solides contiennent:*			
	— substances polluantes au total			9%
	— substances nocives		3%	
	Total		100%	100%

Diagramme du bilan total des substances polluantes

dans les gaz d'échappement:

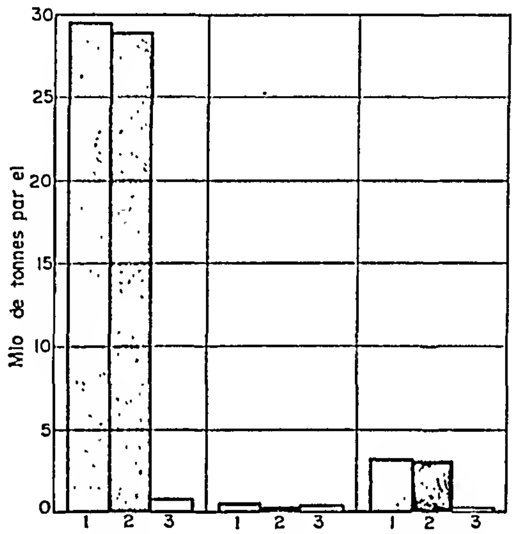
1=au total 29,7 mio de tonnes par an
2=inoffensives 29 mio de tonnes par an
3=nocives 0,7 mio de tonnes par an

dans les eaux usées:

1=au total 0,46 mio de tonnes par an
2=inoffensives 0,2 mio de tonnes par an
3=nocives 0,26 mio de tonnes par an

dans les déchets solides:

1=au total 3,03 mio de tonnes par an
2=inoffensives 3 mio de tonnes par an
3=nocives 0,03 mio de tonnes par an



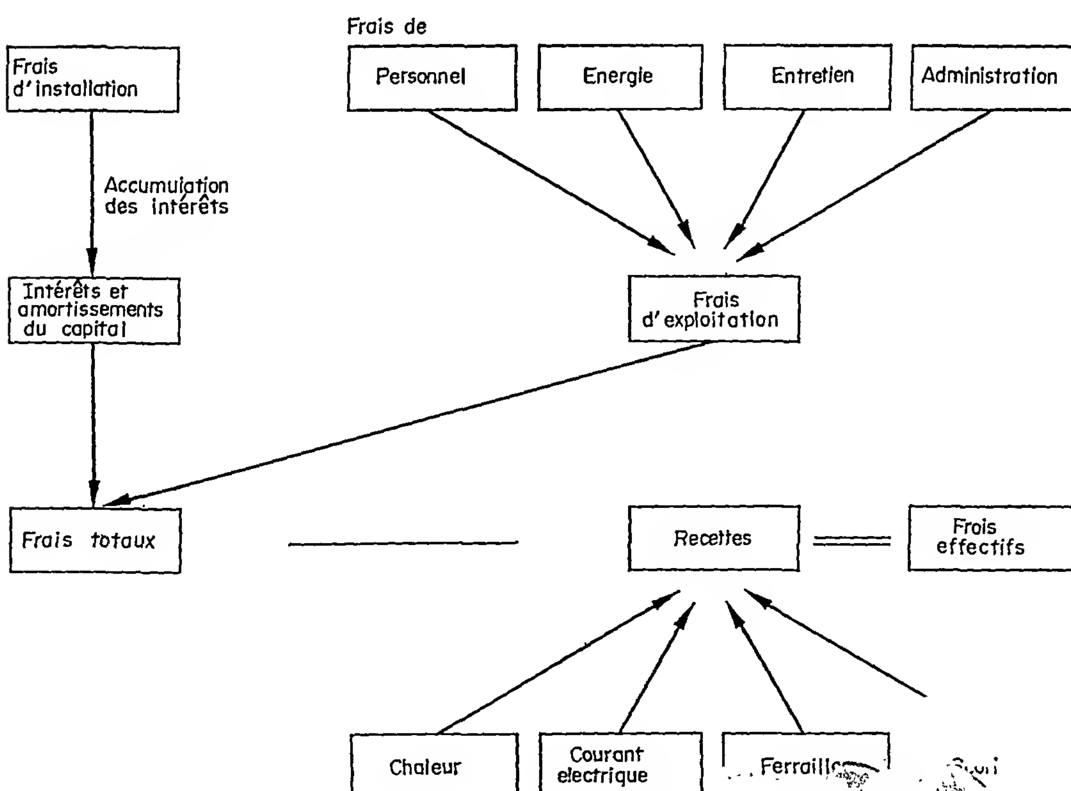
(Situation 1971—Extrait du Rapport technique de la Ligue pour la Propreté en Suisse)

ANNEXE 2

Annexe 2a: Exemple d'un schéma des frais d'une usine d'incinération
Annexe 2b: Subventions de l'Etat dans le secteur de la protection de l'environnement (Suède 1968/69—1972/73—en millions de couronnes suédoises)
Annexe 2c: Exemple de la réduction des frais de traitement par tonne résultant de la capacité accrue de l'usine (Garrett Research and Dev. System)
Annexe 2d: idem, pour le compostage (TPD = tonne par jour)
Annexe 2e: Schéma comparatif des frais de divers systèmes de traitement des déchets
Annexe 2f: Charge imposée à l'environnement dans divers pays (selon la formule Basler)

Annexe 2a

Exemple d'un schéma des frais d'une usine d'incinération



Annexe 2b

Staatliche Zuschüsse im Umweltschutzbereich Haushaltsjahre 1968/9–1972/3 (Mio schw.Kr.)

	68/69	69/70	70/71	71/72	72/73
Umweltschutzforschung (Universitäten und dergleichen nicht einbegriffen)	15,0	17,5	19,0	22,0	28,0
Das staatliche Amt für Umweltschutz	6,1	10,1	12,0	13,4	21,2
Das Konzessionsamt für Umweltschutz	–	0,5	0,5	1,1	1,4
Umweltschutzinformation	0,6	0,7	2,2	2,2	2,2
Sicherstellen und Pflege von Naturschutzgebieten	9,3	14,7	17,7	18,7	21,1
Zuschüsse für kollektive Forschung in den Gewässer- und Luftreinhaltungsbereichen	0,6	0,6	1,2	1,2	1,2
Beihilfen zu kommunalen Kläranlagen	40,0	50,0	60,0	130,0	130,0
Gewässerreinhaltungsuntersuchungen, Seerestaurierungen etc.	4,0	4,0	4,0	4,0	4,0
Zuschüsse für Schutzmassnahmen gegen Wasser- und Luftverunreinigungen in der Industrie	–	50,0	50,0	50,0	50,0
Bereitschaft für Ölbekämpfung zur See	–	–	2,5	5,5	5,5
Die Bezirksregierungen für Naturschutzzwecke	9,7	12,5	14,5	30,6[3]	35,3
Die schwedische Staatsforstverwaltung für Naturschutz- und Freiluftzwecke	0,5	0,6	0,6	0,6	0,6
Wildpflege	4,8	4,9	5,4	5,7	5,7[1]
Die schwedische Arbeitsmarktdirektion für Bereitschaftsarbeiten im Bereich der Naturpflege (Rodung, Landschaftspflege etc.)	9,7[1]	19,7[1]	20,0[2]	25,0[1]	30,0[1]
Das Planwesen (Das Reichsamt für Städteplanung und Bauwesen, Reichsplanung, Regionplanung)	16,0	22,7	24,2	11,1[3]	21,3[4]
Mittel für Anlagen für Sport und Freiluftleben: Anlagenbeitrag Organisationsbeitrag	7,6	9,5	16,5[2]	22,0	23,6
Organisationsbeitrag	30,4	33,4	40,4	45,4	50,9
Die schwedische Arbeitsmarktdirektion für Bereitschaftsarbeiten im Bereich des Sport und Freiluftlebens	16,5[1]	20,0[1]	20,0[1]	20,0[1]	30,0[1]
Das Giftamt	0,4	0,6	1,2	1,4	1,4
Gesamtsumme	171,2	272,0	311,9	409,0	463,4

Annexe 2c et Annexe 2d

Effect of system capacity on operating costs (Garrett Research and Dev. System)

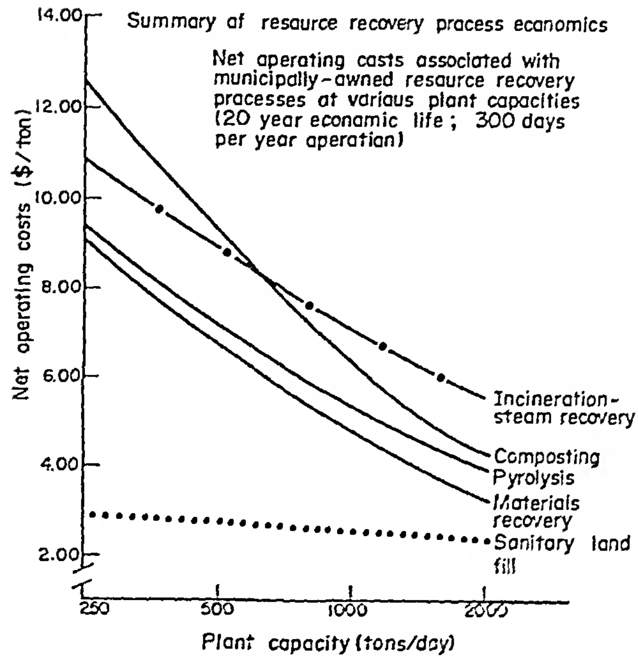
	250 TPD	500 TPD	1000 TPD	2000 TPD
Total annual cost	$1,111,000	$1,911,000	$3,287,000	$5,650,000
Resource value	415,000	830,000	1,661,000	3,322,000
Net annual cost	$696,000	$1,081,000	$1,626,000	$2,328,000
Net cost per ton	$9.28	$7.21	$5.42	$3.88

Composting

	250 TPD	500 TPD	1000 TPD	2000 TPD
Total annual cost	$1,211,000	$1,902,000	$2,987,000	$4,699,000
Resource value	276,000	552,000	1,103,000	2,206,000
Net annual cost	935,000	1,350,000	1,884,000	2,493,000
Net cost per ton	$12.46	$9.00	$6.28	$4.14

Source: *Resource and Recovery: The State of Technology* (Feb. 1973).

Annexe 2e



Process concept	Investment (S000)	Total Annual cost (S000)	Resource value (S000)	Net annual cost (S000)	Net cost per input ton (S)
Incineration and steam recovery	11,607	3116	1000	2116	7.05
Pyrolysis	12,334	3287	1661	1626	5.42
Composting (mech.)	17,100	2987	1103	1884	6.28
Material recovery	11,568	2759	1328	1431	4.77
Sanitary landfill (remote)	2,817	1781	0	1781	5.94

Source: Midwest Research Institute.

Annexe 2f

TABLEAU 11. Charge imposée à l'environnement dans divers pays (selon la formule Basler)

Le potentiel de pollution

Pays	Produit national brut/superficie S/km²
Hongkong	2 500 000
Hollande	750 000
Japon	540 000
Suisse	410 000
Grande-Bretagne	390 000
Italie	240 000
France	180 000
Autriche	140 000
Etats-Unis	100 000
Suède	55 000
Norvège	22 000
Inde	14 000
Canada	7 500
Australie	3 400

Source: Extrait d'une conférence [illegible]
S[illegible], ETHZ, [illegible]

ANNEXE 3

Rapport sur le voyage d'étude organisé par la Ligue pour la Propreté en Suisse pour la visite des usines de traitement des déchets de la Ville de Rome.

Texte: D. Stickelberger/IRC-WHO et W. Moser/Ligue pour la propreté en Suisse.
Photos: G. Rollé/EAWAG et W. Moser/Ligue pour la propreté en Suisse.
Rédaction: W. Moser.
Zurich, le 23 novembre 1973

1. *Service de ramassage des ordures de la Ville de Rome*

La collecte des déchets communaux (des ménages, ateliers, etc.) des 2,9 millions d'habitants a lieu 7 jours par semaine, c'est-à-dire y compris les dimanches et les jours fériés. Le parc de camions de ramassage comprend 600 véhicules et, chaque jour, 1250 membres du personnel de voirie (au total 1800 personnes) sont sur pied pour la collecte des déchets.

Comme récipients, seuls les sacs en polyéthylène sont tolérés (sacs de 110 l pour les grand immeubles locatifs, etc., et sacs de 35 l pour les habitations particulières et les ménages individuels). Chaque jour, les ouvriers de la voirie collectent entre 200 000 et 250 000 sacs de 110 l et distribuent en même temps les nouveaux sacs vides. Le prix des sacs est compris dans la taxe municipale, taxe qui se monte à 11 000 Lires par habitant et par an (recettes totales: environ 30 milliards de Lires).

Les frais totaux de ramassage des ordures, nettoiement des voies publiques, etc., se montent à environ 35 milliards de Lires. L'excédent des dépenses est couvert par le produit des impôts.

Les distances entre les centres de ramassage et les usines de traitement des déchets sont de 16 à 30 km. Les usines sont situées à l'est et à l'ouest de la ville, chacune à environ 17 km du centre de Rome.

2. *Les usines de traitement des déchets*

Le traitement des déchets municipaux—il y en a environ 2200 t par jour—s'effectue dans quatre usines, les 3/4 des déchets étant traités dans trois usines de recyclage (environ 1600 t/jour) et le reste dans une usine de compostage (environ 600–700 t/jour).

L'usine de compostage et une des usines de recyclage se trouvent à l'ouest de la ville, les deux autres usines de recyclage à l'est (voir illustration No. 1).

2.1. *Collaboration entre les autorités municipales et les entreprises privées*

Les trois usines de recyclage sont des entreprises privées qui se sont associées en une sorte de consortium. L'exploitation et l'administration sont assurées par des employés engagés et rémunérés par les entreprises privées en question.

De son côté, la municipalité exploite l'usine de compostage et se charge de l'enlèvement des ordures. Les modalités de ce système de collaboration sont réglées par un contrat de 15 ans, la municipalité s'étant toutefois réservé le droit de résilier le contrat avec préavis d'une année.

En signant le contrat, la municipalité s'est engagée à assurer le ramassage des déchets et à les livrer aux usines de traitement. D'autre part, le groupe d'entreprises privées s'est engagé à traiter et recycler les déchets.

2.2. *Modalités d'ordre financier*

Le problème des frais a été résolu par un arrangement certainement unique en son genre.

— La Ville de Rome paie, par tonne de déchets livrés, 50 % des frais de traitement. Il faut noter à ce sujet que les frais d'incinération considérés comme usuels en Italie se montent à 7000–8000 Lires par tonne (en novembre 1973, la municipalité paie par exemple 3480 Lires par tonne de déchets livrés).
— Le solde de 50 % est couvert par la vente des matières premières et des produits qui, après récupération et traitement dans les usines da recyclage, sont redevenus utilisables.
— Le total des recettes est de l'ordre de 7000–8000 Lires par tonne (coût de base de l'incinération).

Et voici encore quelques indications qui montrent encore mieux combien ces modalités sont vraiment uniques en leur genre:

— Pour chaque matière recyclable (actuellement le fer (ferrailles), le papier et les fourrages concentrés) on établit une cote fixe (pourcentage qui, chaque année, est adapté aux nouvelles possibilités offertes par la technologie).
— Pour la vente des matières et produits récupérés et traités, on se base sur les prix officiels indiqués par la Chambre de Commerce. Ces prix sont révisés tous les quatre mois (ferrailles, papier brut, maïs pour les fourrages concentrés).
— Si, par exemple, les prix en vigueur sur le marché augmentent de 50 % (soit pour l'un ou l'autre des produits, soit pour tous les trois), la municipalité paie, par rapport à la cote de recyclage fixée pour chaque catégorie de matières, une participation de 50 % moins élevée, puisque les produits recyclés peuvent dès lors être revendus à 150 %, au lieu de 100 % comme fixé précédemment.

Exemple: papier

Hypothèses: cote fixe de recyclage pour 1973 = 10 % de la quantité totale des déchets,
le prix du marché pour le papier brut subit une augmentation de 50 %.

La municipalité paie alors, durant les quatre mois suivants, une somme de 50 % moins élevée pour 10 % de la totalité des déchets livrés;

ou, en d'autres termes:

au lieu de 3600 Lires par tonne pour cette portion de 10 % des déchets—portion qui se monte aujourd'hui à 160 t—la municipalité ne paie plus que 1800 Lires par tonne.

En outre, les usines de recyclage sont libres de fixer ellesmêmes les prix de vente.

2.3. *Structure et capacité des usines de traitement et recyclage*

Les usines ont été mises en service il y a soit 10 ans, soit 7 ans, et, depuis, elles ont été constamment agrandies et modernisées. Ci-après est reproduit le schéma du déroulement du traitement, déroulement qui est en principe le même dans chacune des trois usines, les seules variations se rapportant aux capacités, au nombre de machines et aux types de machines.

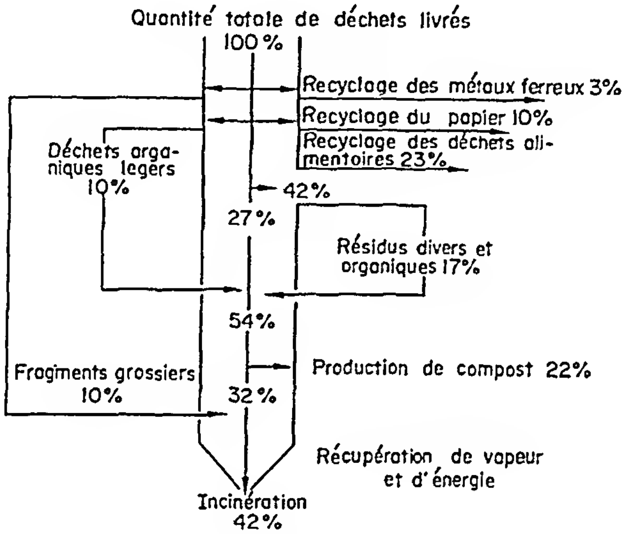
Quantité totale de déchets livrés: env. 2200 t/jour (100 %) dont:

env. 30 % de déchets de papier et de carton,

env. 45 % de déchets organiques,
env. 3 % de déchets métalliques (dont env. 10 % de métaux non-ferreux),
env. 5 % de déchets de verre,
env. 5 % de déchets de matières plastiques,
env. 12 % de matières diverses.

On observe d'une manière générale que les déchets organiques ont tendance à diminuer continuellement (en 1960, les gadoues contenaient encore 60-65 % de matière organique), alors que la teneur en papier et matières plastiques est en augmentation constante.

Schéma du traitement des déchets tel qu'il est effectué aujourd'hui à Rome:



On prévoit d'ajouter prochainement au système les éléments suivants, dont quelques-uns sont déjà en construction:
— ligne de récupération des déchets de verre,
— ,, ,, ,, de matières plastiques,
— agrandissement de la récupération du papier (augmentation de la capacité),
— installation de traitement des boues d'épuration.

2.4. *Déroulement des opérations*

Les camions de ramassage déchargent les sacs à ordures dans un petit silo. De là, les sacs parviennent dans une installation à double voie où ils sont ouverts. L'installation en question consiste (1) en couteaux parallèles, (2) en un tambour rotatif muni de crochets. Pour empêcher les émissions de poussière, on a recours à des apports de vapeur. Il est indispensable d'ouvrir et déchiqueter les sacs avant de pouvoir procéder au triage. Il y a quatre étapes de triage:
— 1er triage: extraction des fragments grossiers,
— 2me triage: extraction des métaux par bande magnétique,
— 3me triage: extraction du papier et des déchets de matières plastiques,
— 4me triage: séparation aussi poussée que possible entre le papier et les déchets de matières plastiques.

(a) *Incinération.* La portion de déchets incinérés se monte à environ 42 % des quantités totales de déchets livrés aux usines de traitement des déchets de Rome.

Capacité: un four à 60 t/jour, dimensionné et réglé pour produire 1500 kgcal/kg
2 fours à 100 t/jour, dimensionnés et réglés pour produire 2500 kgcal/kg.

Température d'incinération: env. 900°C

Rendement de la chaudière: 2×4500 kg de vapeur à l'heure,
1×1000 kg de vapeur à l'heure

Pression de la chaudière: 6 atm.
80 %de la vapeur produite sont utilisés dans. l'usine elle-même,
et 20 % sont vendus à l'extérieur.

Les fours travaillent 7 jours par semaine, à raison de 24 h. par jour.

Il suffit à l'usine de brûler 3 % des quantités totales de déchets pour produire la quantité de vapeur requise pour l'exploitation (les 70 % qui restent seront recyclés à l'avenir).

(b) *Recyclage des métaux ferreux.* La teneur des déchets en métaux ferreux est de 3 % environ. Le taux d'extraction atteint par la séparation magnétique est de 90 % env.

1t de métaux ferreux produit en moyenne environ 800 kg de ferrailles pouvant être vendues. Il y a environ 35–40 t de métaux ferreux dans les déchets livrés chaque jour aux usines.

Déroulement des opérations: Les métaux ferreux extraits des déchets sont flambés dans un four rotatif spécial, puis désétamés (à la température de 600–700°C). Les ferrailles ainsi produites, qui sont de qualité étonnamment pure, sont pressées en blocs, puis acheminées par camions vers les aciéries.

L'installation travaille 6 jours par semaine, à raison de 6–7 h. par jour.

(c) *Compostage.* La teneur des déchets en matières compostables est d'environ 22 %. Avec 1 t de matières compostables on produit environ 630 kg de compost.

Déroulement des opérations: Le compost est produit selon la méthode habituelle de compostage en tas d'une hauteur de 130 cm. Le groupe d'entreprises possède une "Hacienda" de 150 ha, dont 40 ha sont utilisés comme aire de compostage. Grâce à une machine spécialement construite, à spirales concentriques, le retournement des tas—pour l'aération du matériel—s'effectue automatiquement et rapidement.

L'usine de compostage travaille 16 h. pendant les 6 jours de semaine (2 équipes) et 6 h. le dimanche.

(d) *Production de fourrage concentré* (recyclage des déchets alimentaires). La teneur des gadoues en déchets alimentaires est d'environ 23 %. Avec 1 t de ces déchets, on produit environ 200 kg de fourrage concentré.

Déroulement des opérations: Les déchets sont lavés, puis séparés par flottation du papier, des matières plastiques, etc. Ils sont ensuite lavés une seconde fois, puis pressés (ce qui permet d'en extraire 15 % de la teneur en eau), puis entreposés dans un silo intermédiaire. Par la suite, ils sont stérilisés dans des autoclaves (il y a en tout 26 autoclaves dans les 3 usines), processus qui dure deux heures et se déroule à 130°C (les autorités de Santé Publique prescrivent 20 minutes et 120°C). La durée plus longue et la température plus élevée utilisées par l'usine de recyclage modifient la consistance physique du matériel et créent des conditions idéales pour la suite du traitement. Après séchage à 80–90°C (qui réduit à 50 % la

teneur en eau), le matériel passe successivement dans un moulin à marteaux, un crible vibratoire, un appareil aspirateur et arrive dans un silo intermédiaire. Il contient maintenant 98 % de matière biogène et 2 % de matière inerte (la limite de tolérance est d'environ 10 %).

Le fourrage concentré, qui se présente sous forme pulvérulente, est transformé en dragées par un procédé utilisant une forte pression, des apports de vapeur et, éventuellement aussi, des additions de protéines (environ 10 %). Les dragées sont, soit entreposées dans un silo, soit mises dans des sacs pour le transport à l'extérieur. La valeur nutritive du fourrage concentré correspond à 70 % de celle du maïs.

Pour économiser l'énergie et la chaleur, les installations travaillent 24 h. par jour pendant 6 jours chaque semaine.

(e) *Recyclage du papier.* La portion de papier dans la quantité totale des déchets livrés aux usines de traitement est d'environ 10 %.

Il est possible de recycler environ 75–80 % de la quantité totale du papier contenu dans les gadoues.

Avec une tonne de papier, on produit environ 820 kg de cellulose réutilisable dans la fabrication du carton.

Déroulement des opérations: Après la séparation mécanique et automatique des matières plastiques, le papier—qui contient encore un faible pourcentage de matières plastiques—est pressé en balles et conduit par bande convoyeuse vers les "pulpers" (machines qui le transforment en pâte). Comme les matières plastiques ne se dissolvent pas dans les pulpers, elles peuvent être extraites assez facilement. Pour la préparation de la cellulose, l'extraction des particules étrangères, la déshydratation, etc., on a recours aux méthodes conventionnelles.

La masse de cellulose est acheminée directement vers les fabriques de carton et carton ondulé.

On est en train d'agrandir l'installation pour en doubler la capacité.

Les installations de récupération du papier et de préparation de la cellulose travaillent 6 jours par semaine à raison de 24 h. par jour.

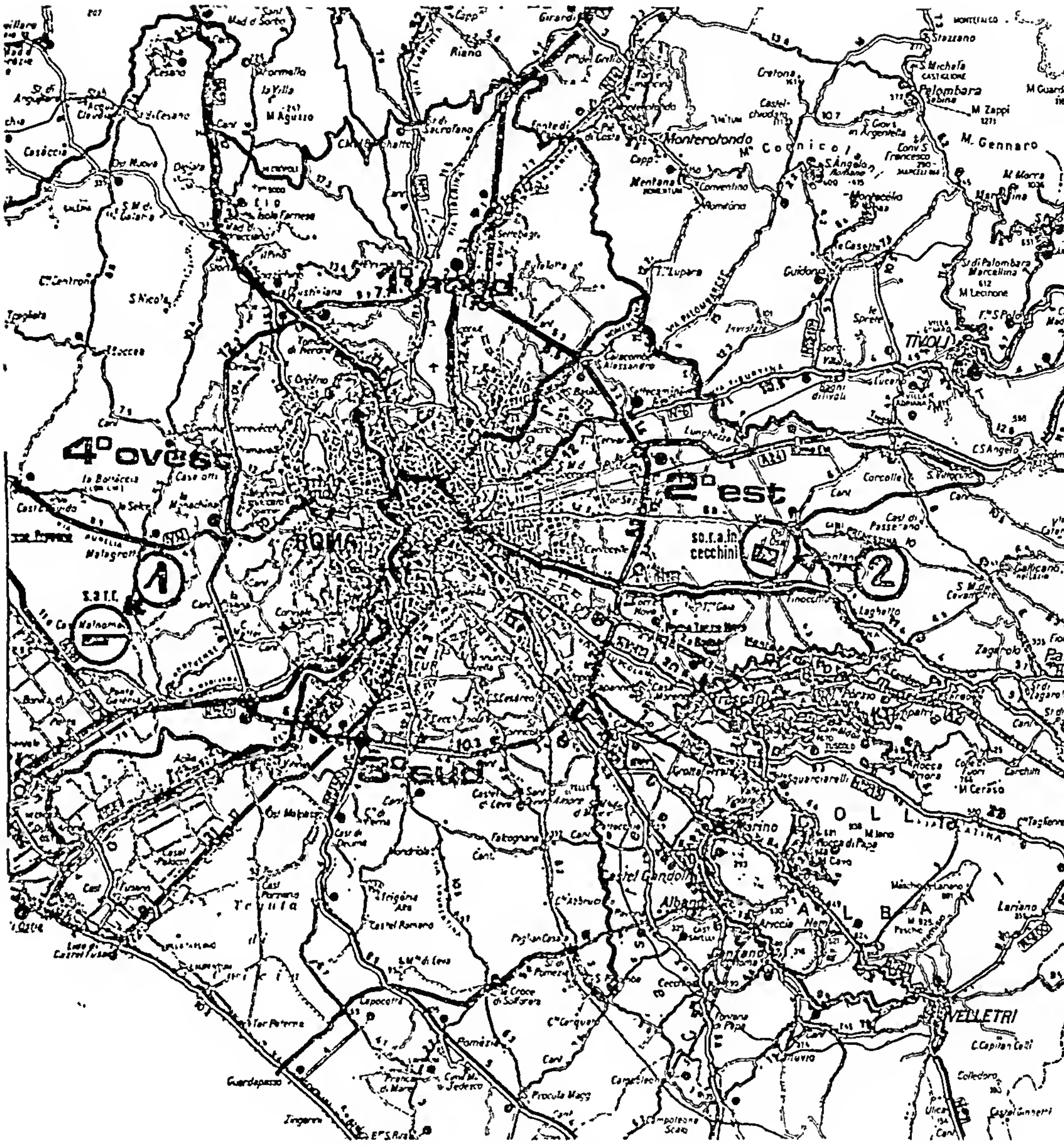
2.5. *Besoins en personnel, investissements, frais d'entretien, consommation d'eau et production d'énergie*

Les besoins actuels en personnel pour toutes les installations (y compris la planification et l'administration) sont calculés sur la base d'une personne pour 6 tonnes de déchets. Une fois que les installations auront été agrandies pour atteindre la pleine capacité, il faudra compter une personne pour 10 tonnes.

Les frais d'investissements pour les usines de recyclage correspondent à peu près à ceux d'une grande usine d'incinération. Pour une installation pouvant traiter 600 t de déchets par jour, les investissements se montent à 6 milliards de lires, les frais d'entretien sont d'environ 20–30 % inférieurs à ceux des usines d'incinération.

L'épuration des gaz de l'usine d'incinération nécessite une consommation quotidienne d'eau d'environ 1 m^3/t. Dans toutes les autres usines, l'eau est recirculée en cycle fermé (100 %). L'eau est épurée par oxydation et sédimentation dans les usines elles-mêmes.

Avec l'énergie récupérée dans l'usine d'incinération (vapeur), on couvre la totalité des



Long-range Mineral Resources.

besoins de toutes les usines du groupe. La consommation d'énergie est d'env. 12 kWh/t. L'excédent (env. 15–20 %) est livré à une fabrique avoisinante.

Abb. 1. (1) Doppelanlage im Western der Stadt—Kompostieranlage, Kapazität *ca.* 700 Tagestonnen, —Recyclinganlage, Kapazität *ca.* 400 Tagestonnen.

Fig. 1. (1) Usine double à l'ouest de la ville.—usine de compostage, capacité env. 700 t/jour,—usine de recyclage, capacité env. 400 t/jour.

Ill. 1. (1) Double plant in the western part of the city—composting plant, capacity approx. 700 t/day,—recycling plant, capacity approx. 400 t/day.

Abb. 1. (2) Doppelanlage im Osten der Stadt—2 Recyclinganlagen, Kapazität je 600 Tagestonnen.

Fig. 1. (2) Usine double à l'est de la ville—2 usines de recyclage, capacité 600 t/jour chacune.

Ill. 1. (2) Double plant in the eastern part of the city—2 recycling plants, capacity approx. 600 t/day each.

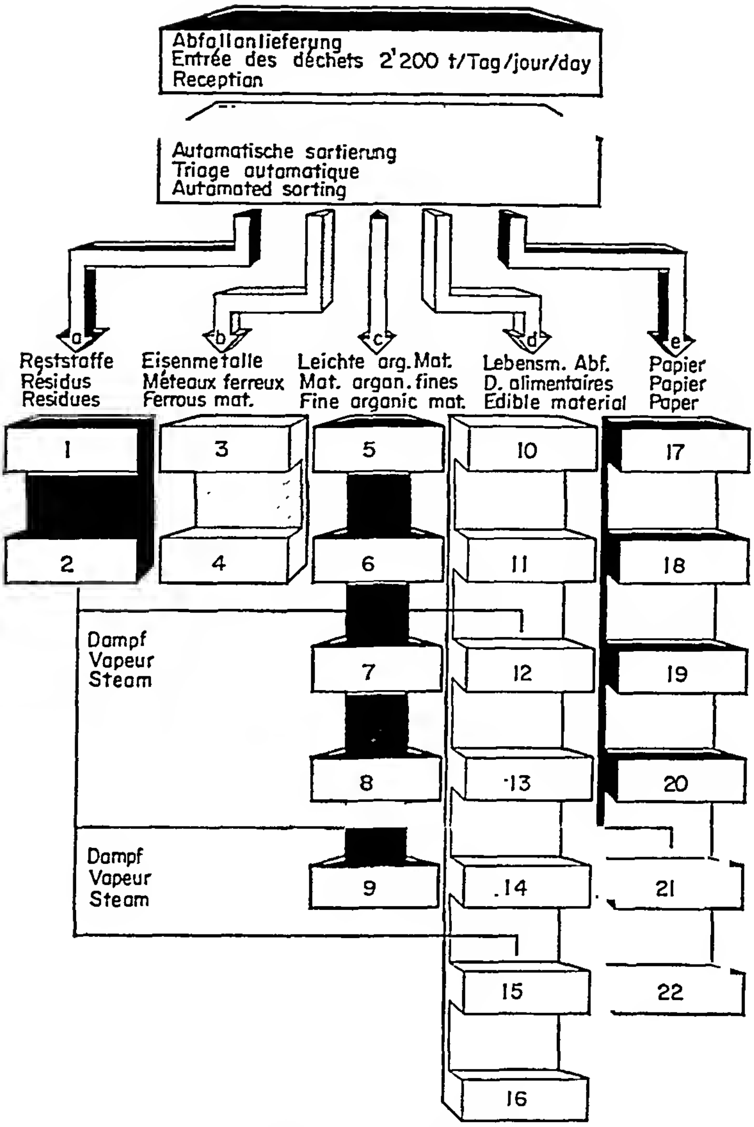


Abb. 2 Fig. 2 Ill. 2
Fig. 2. Long-range Mineral Resources.

Abb. 2 / Fig. 2 / Ill. 2

(a) *Reststoffe / Résidus / Residues*
 1) Verbrennung / Incinération / Incineration.
 2) Dampferzeugung / Production de vapeur / Steam production.

(b) *Eisenmetalle / Métaux ferreux / Ferrous material*
 3) Ausbrennung und Entzinnung / Flambage et désétamage / Burnout and detinning.
 4) Schrottverpressung / Compactage / Bailing.

(c) *Leichte organische Materialien / Matière organique fine / Fine organic material*
 5) Zerkleinerung und Homogenisierung / Broyage et homogénéisation / Grinding and homogenizing.
 6) Fermentierung / Fermentation / Fermenting.
 7) Reinigung / Epuration / Purifying.
 8) Mietenaufschüttung / Mise en tas / Stoking.
 9) Reifung / Maturation / Curing.

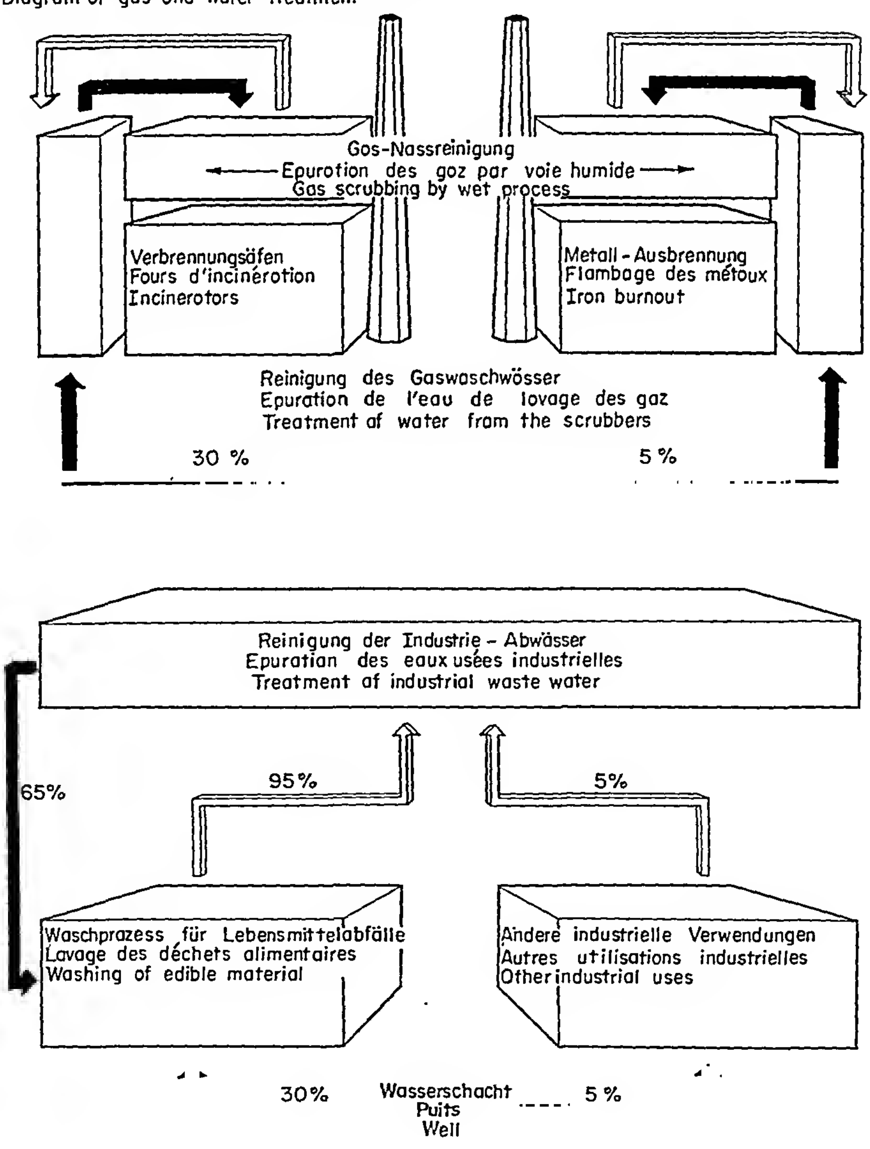
(d) *Lebensmittelabfälle / Déchets alimentaires / Edible material*
 10) Waschprozesse / Lavages / Washing.
 11) Sterilisation / Stérilisation / Sterilizing.

12) Trocknung / Séchage / Drying.
13) Reinigung / Epuration / Purifying.
14) Pulverisierung / Pulvérisation / Pulverizing.
15) Tabletten- (Dragees-) Herstellung / Confection de dragées / Pelleting.
16) Abpackung / Empaquetage / Bagging.

(e) *Papier / Papier / Paper*

17) Ballenpressung / Mise en balle / Baling.
18) Zellstoffaufbereitung (Pulper) / Préparation de la pâte de papier / Pulping.
19) Reinigung / Epuration / Purifying.
20) 1. Eindickung / premier Epaississement / 1° Thickening.
21) Homogenisierung / Homogénéisation / Homogenizing.
22) 2. Eindickung / second Epaississement / 2° Thickening.

Schema der Abgas- und Abwässerreinigung
Schéma de l'épuration des gaz et des eaux usées
Diagram of gas and water treatment



ANNEXE 4

Tidiness and the Better Management of Resources

Speaking notes of Wolfgang Moser, General Secretary of the Keep Switzerland Beautiful Organization

The Vicious Circle

Raw materials extraction:
(a) extraction of unrenewable natural resources (such as metals, mineral oil, rocks, sand, etc.)
(b) excessive exploitation of renewable natural resources (such as vegetal and animal products)

Environmental stress and direct and indirect detrimental effects
damage to the landscape (caused by mines, gravel pits, deforestation, etc.) in the form of alterations, disturbances in the equilibrium of nature, erosion, transformation into steppes, etc.
solid, liquid, and gazeous wastes
degradation of the landscape caused by uncontrolled dumps
extermination of animal and vegetal species
energy consumption, thermal pollution, noise

Transport environmental stress

Raw materials utilization:
(a) processing of raw materials toward their utilization in the production of goods (e.g. metal ore, crude oil, wood, etc.)
(b) direct processing of raw materials in the production of goods

Environmental stress and direct and indirect detrimental effects
solid, liquid, and gaseous wastes
energy consumption, thermal pollution, noise
degradation of the landscape caused by uncontrolled dumps

Transport environmental stress

Utilization of animal and vegetal resources (agriculture, livestock husbandry, etc.)
environmental stress and direct and indirect detrimental effects

Consumer goods industry:
(a) production, processing, packaging (packaging for protection, storing and transport)
(b) distribution (wholesale and retail)

Environmental stress and direct and indirect detrimental effects
solid, liquid and gaseous wastes
energy consumption, thermal pollution, noise

Transport environmental stress

Consumption of goods:
(a) Food, combined with non-food in the form of packaging
(b) Non-food (utility and luxury goods), also combined with packaging material

Environmental stress and direct and indirect detrimental effects
solid, liquid and gaseous wastes
energy consumption

Wastes

Environmental stress and direct and indirect detrimental effects

Tidiness and the Better Management of Resources=
Tidiness (reduction of pollution and littering in nature and landscape) and Reduction of the Environmental Stress
this should, in my opinion, be the proper title for Discussion III.

If we want to reduce or partly prevent the environmental stress in general and landscape degradation in particular, there is only one solution, namely to try *to remove the causes* instead of applying symptomatic therapy.

The cleverest methods of information and education, the best organized campaigns and the most sensational techniques *are of no use whatever* if no attempt is made at the same time to pull out the roots of the malady that is slowly but surely destroying the environment.

What does this specifically imply—for instance, in the case of *landscape degradation*? The present "throw away" and "use wastefully" trend must be slowed down and finally brought to a stop.

Results:

Reduction of the amounts of waste and, consequently, of the environmental stress at each of the stages of the flow of materials (or of the vicious circle).

General reduction of the consumption of goods.

Intensified production of more durable and stable goods.

More carefulness in dealing with goods, better utilization, better service (repairing and maintenance).

Less expenditure of raw materials per item produced,
and, for instance, as regards *future measures*?

Truly effective measures of environmental protection and conservation should be encouraged and put in practice, either on the initiative of people or organizations, or by virtue of laws and regulations.

This means that:

The interests of the environment should be put on a par with economical interests (and not on an inferior priority level as has generally been done until today).

Each individual should show more concern for the environment by his attitude and behaviour, and should even put the interests of the environment before his own selfish and material interests.

THE ENVIRONMENTAL EFFECTS OF RECENT DEVELOPMENTS IN THE TREATMENT OF URBAN REFUSE

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In this necessarily brief review of the environmental considerations of urban refuse treatment, I will look at each type of method separately—traditional means, incineration and pyrolysis, composting, reclamation.

TRADITIONAL METHODS

Man has dumped refuse since the day he started to produce it and tipping is still the primary method of waste disposal throughout the world. Crude tipping—the haphazard dumping of waste in a convenient hole in the ground or unwanted space—gives rise to odours, windblown debris, vermin, flies and other insects, pollution of ground and surface water as well as the continual threat of fire within the tip.

Many of these evils are minimized to a variable extent in controlled tipping where refuse is deposited in layers and compacted, a top covering of soil or rubble sealing the surface. Controlled tipping can and does assist significantly in the reclamation of land, but it does give rise to environmental problems. As refuse is a heterogeneous collection of material, harmful substances may well be present and these can leach out as rain percolates through the tip. In Britain, where one-third of the nation's water supplies is drawn from ground water resources, the Department of the Environment Working Party on Refuse Disposal established to its satisfaction that pollution of ground water by tip percolate can occur. This has to be considered seriously because in Britain and elsewhere ground water is used for human consumption after preparation amounting usually to no more than sterilization.

Surface drainage from tips gives rise to pollution of rivers and streams, sometimes causing de-oxygenation and the growth of sewage fungus downstream from the tip. Problems of water pollution can be avoided, at least in part, by careful selection of the tipping site or if the base of the tip is lined with puddled clay.

Tipping into wet pits presents greater risks to ground water pollution because the quantity of polluting material is greater and is more easily extracted; it is also often brought into direct contact with the water table.

Among the problems associated with landfill disposal is the creation of voids in tips and resistance to compaction. Large plastics containers, for example, which are not degradable, can cause voids which later give rise to subsidence in the tip. Old tyres can cause difficulty owing to their elasticity. Use of old tipping or sewage-disposal sites for housing and other development has revealed topsoil and subsoil contamination from heavy metals and other potentially harmful substances.

Problems of methane gas generation within a tip can arise and as the organic matter in a dump will attract birds—particularly seagulls—tips sited close to airports have presented a very real danger to aircraft.

To methods of crude and controlled tipping must be added the modern techniques of pulverization. Reducing the size of refuse by shredding or other pulverization processes can make compaction easier and obviate the problems of voids. Pulverized refuse can be more easily controlled in landfill, is less attractive to insects and rodents and can be deposited on sites where tipping of crude refuse would be quite unacceptable. Biological breakdown tends to be accelerated.

Pollution of surface or groundwater can nevertheless occur, presence of heavy metals in the sometimes widely spread deposit casts doubt on the future suitability of such ground for any form of agricultural use, and unless pulverized refuse is covered, nuisance is likely to be caused by windblown fragments. Odour can also be a problem and there is evidence that an inert sealing medium is really needed to cover deposits of pulverized refuse.

None of these tipping procedures seems to me to be acceptable to any society that regards itself as civilized.

INCINERATION

Destruction of refuse in large incinerators has developed steadily over the last decade, although the efficiency of these plants is often questionable. Certainly the older installations are frequently extremely inefficient, causing atmospheric pollution, through ineffective combustion.

Solids or particulate emissions are the most visible pollutants. According to American measurements 1 ton of refuse burned in a conventional incinerator produces an average of 24 lb of particulate. Newer plants reduce that figure considerably but additional environmental safeguards tend to increase the cost of an already relatively high-cost form of refuse treatment.

Generation of toxic gases in combustion of plastics has received a good deal of attention. Burning at fairly low and variable temperatures can be potentially hazardous, but the evidence of modern incineration practice at higher temperatures points to minor problems in this respect. Fears of generation of phosgene gas seem to be groundless. Tests in the United Kingdom showed that with 0.9% plastics by weight in mixed refuse, hydrochloric acid concentration in incinerator exhaust was only 3 ppm. Of the plastics incinerated, one-third were chlorine containing; the rest were carbon–hydrogen–oxygen plastics.

Of course, incineration leaves a residue—1 ton of refuse produces up to 500 lb of residual material. This contains various metallic elements and any ferrous metal in it will be contaminated by phosphorus that was not present before the incineration took place. Phosphorus is not a desirable element in steelmaking and thus ferrous incinerator residue has to be avoided for general steelmaking and ironmaking purposes.

PYROLYSIS

Pyrolysis offers many attractions, not the least of which is that it produces no air pollution. The process yields solids, liquids, and gases. According to the United States Bureau of Mines, 1 ton of refuse pyrolysed at 1600°F yields some 18,000 ft^3 of gas, 114 gal of liquid, 25 lb of ammonium sulphate, 0.5 gal of tar and 154 lb of solid residue. The only pollution problem would appear to be presented by the liquid which is around 90% water plus a mixture of numerous organic compounds. The mixture is complex and to some extent unpredictable in nature. It has been suggested that this liquid could be utilized as a wood preservative or insecticide and this seems essential unless either further processing to render it safe or absolutely reliable disposal can be arranged.

COMPOSTING

Although composting has aroused enthusiasm from time to time it has, with isolated exceptions, failed to make any real impact on the picture of waste disposal throughout the world. Demand for the product of municipal composting plants has tended to be slim which, in the light of research carried out by Edinburgh University at the School of Agriculture there, is probably a very good thing. This research has established that the organic matter in municipal compost is not humus but blackened paper. When added to soil it may produce an effect opposite to that of fertilizer—a demand for nitrogen is generated by micro-organisms which proceed to degrade the cellulose in the compost. The presence of small particles of glass is another drawback, but is in my view of minor significance when compared with the existence of relatively high and variable trace elements of boron, copper, lead, nickel, and zinc.

The work at Edinburgh has shown that this material can contain up to 300 times as much available zinc and lead and 100 times as much available boron and copper as uncontaminated rural soils. Even a moderate dressing of 10 tons an acre has been shown to have a pronounced effect on trace elements in the soil. Evidence suggests that once these elements are introduced, with the exception of boron, they are not readily leached out. In essence, the research suggests that repeated applications of municipal compost to agricultural land are undesirable because of the presence of metals which will build up in the soil and could be hazardous.

Several methods of composting on a municipal scale are employed or have been propounded. The product of one pilot-scale plant built in the United Kingdom was analysed by an independent laboratory which found it so heavily contaminated by copper that any land treated with it would be rendered infertile.

The totally unpredictable nature of refuse content and the known existence of injurious metallics in garbage in my view makes composting an environmentally hazardous technique.

RECLAMATION

Refuse reclamation systems represent an area of development that in world terms is just in its infancy. In general, where recovery is practised it is limited to reclaiming a few constituents of the refuse, such as paper and board and ferrous metals. In the United States, however, a number of very much more comprehensive systems have been introduced, mechanized in nature and based on either the wet or dry separation of garbage.

From what limited information is available, it seems that these processes will fulfil their promise in reducing the environmental impact of refuse treatment to a very low level indeed. This is provided, of course, that design criteria employed provide for closed separation systems.

In my view the logic of recycling needs no emphasis. The problem is to make it work in practical terms. A plant for recovering a maximum of useful materials contained in refuse can be as environmentally acceptable as any modern industrial installation. In certain cases odour might be a difficulty and if material is shredded at any stage in the process, there are likely to be problems of noise and vibration. But with proper attention to choice of site and adequate landscaping these could be overcome.

At the present stage of technological development, however, one fact has to be faced. Almost all recycling or recovery processes generate their own waste. In some cases these may be toxic or otherwise hazardous, and they are in any case likely to be quite highly concentrated. Incineration or pyrolysis could no doubt be employed to process many such wastes beyond any state of potential danger.

So far solutions to the problems of waste treatment have tended to be less than comprehensive. I suggest that if they are to work in practical, economic, and environmentally advantageous terms they must be fully comprehensive. There must be no gaps left in the processing sequence.

It seems to me that refuse reclamation must be developed in the light of knowledge far beyond that of the engineer. At the moment techniques of separation and preparation are regarded almost totally as his province. The biologist has an enormous contribution to make in structuring a scheme of refuse reclamation and utilization that is total rather than partial and which fits naturally into the environment. I believe this to be an area of investigation of primary importance.

APPENDIX

Data from Edinburgh University on Metallic Contamination of Soil Treated with Municipal Compost

TABLE 1. Trace-element levels (ppm) in municipal composts and rural arable soil

Reference		Water extractable	EDTA extractable	Acetic acid extractable		
		Boron	Copper	Lead	Nickel	Zinc
Edinburgh	(1)	3.8	83	31.5	8.2	400
	(2)	5.0	81	51.6	9.1	463
	(3)	34.2	332	88.7	13.0	475
	(4)	100	74	27.4	12.9	515
	(5)	66	105	37.5	20.1	655
	(6)	94	44	67.3	7.1	425
Midlothian	(1)	5.6	162	24.8	20.6	513
	(2)	7.2	84	27.1	17.4	535
	(3)	9.4	76	39.9	18.7	420
Milan		—	229	215	—	798
Rural arable soil		1	3	0.5	1	3

TABLE 2. Mean concentrations in air-dry soil sampled at harvest

Experiment	Treatment, tons/ha municipal compost	Copper, ppm EDTA extractable	Zinc, ppm acetic acid extractable	Boron, ppm water extractable
Cabbages 1968	0	2.6	2.5	0.5
	25	3.0**	2.8 NS	0.7**
	50	3.2***	3.9**	0.7***
Cabbages and lettuces 1969	0	6.7	7.6	0.8
	50	5.6 NS	9.2*	2.6*
	100	6.9 NS	11.6***	4.4***
Dwarf kidney beans 1969	0	3.9	5.5	0.7
	50	4.5 NS	8.0**	1.8**
	100	5.2**	11.1***	3.9***
Potatoes 1970	0	3.3	4.2	0.7
	50	10.7***	16.2**	3.0***
	100	13.9***	27.4***	5.4***
Peas 1970	0	4.7	5.0	0.7
	50	20.5***	49.3**	5.8***
	100	39.2***	124.0***	10.8***

TABLE 3. Mean concentrations in oven-dry lettuces

Treatment, tons/ha municipal compost	Copper, ppm	Zinc, ppm	Boron, ppm
0	8.7	64.0	24.7
50	11.5*	66.8 NS	29.7**
100	11.6*	70.8**	33.0***

TABLE 4. Mean fresh weight yield of beans (g) plot

Treatment, tons/ha municipal compost	Total aerial bean plants	Bean pods
0	4065	1720
50	2906*	1108**
100	1155***	368***

TABLE 5. Mean concentrations in oven-dry beans

Treatment, tons/ha municipal compost	Pods			Leaves and stems		
	Copper, ppm	Zinc, ppm	Boron, ppm	Copper, ppm	Zinc, ppm	Boron, ppm
0	6.90	38.5	28.0	10.2	54.8	43.7
50	6.95 NS	39.7 NS	43.0***	11.2 NS	60.9*	131.5**
100	7.75 NS	43.0***	55.7***	12.8**	64.5**	205.4**

Levels of significance are based on comparisons with control levels: *=P<0.05, **=P<0.01, ***=P<0.001, NS=Non-significant.

TABLE 6. Fresh weight yields of potato tubers

Treatment, tons/ha municipal compost	Mean yields/plot, kg
0	8.39
50	9.48**
100	9.43**

TABLE 7. Oven-dry yields of peas

Treatment, tons/ha municipal compost	Mean yields/plots (g)	
	Peas and pods	Leaves and stems
0	200	548
50	296*	560 NS
100	296*	584 NS

TABLE 8. Mean concentrations in oven-dry potatoes

Treatment, tons/ha municipal compost	Haulms			Tubers	
	Copper	Zinc	Boron	Copper	Zinc
0	6.6	34.5	29.3	2.9	9.5
50	7.2 NS	42.6**	36.1***	3.3*	11.3*
100	7.4*	45.8***	42.6***	3.6**	12.3**

These results indicate significant enhancement of copper, zinc, and boron in potato haulms and copper and zinc in the tubers. The levels of boron in the tubers were too low for accurate determination.

Levels of significance are based on comparisons with control levels: *=$P<0.05$, **=$P<0.01$, ***=$P<0.001$, NS=Non-significant.

PREDICTING SOLUTE TRANSPORT IN SUBSURFACE WATERS

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INTRODUCTION

In order to arrive at a desirable set of policies and procedures for solving "growth"-generated environmental problems (that is, problems due to population growth, higher per capita consumption and the changing technology), all the available techniques and options should be explored. In particular, in connection with problems of mineral-resources utilization and waste-product disposal, considerations of measures like conservation, reuse and recycling will have to include, for technical reasons and in response to economic pressures, analyses of various supporting and alternative operations. One such analysis certainly will call for assessing the environmental impact of accidental or controlled waste-product incorporation into the subsurface layers of the earth. Assessment of this kind concerns itself largely with the dangers of polluting useable groundwater resources. Among other things, it takes into consideration the possibility of moderating or eliminating such dangers by utilizing the dispersive, pollutant-fixing and pollutant-degrading capabilities of the subsurface zones. The analysis in question requires the capability to predict, as quantitatively as possible, the course of solute transport and the resulting pollutant concentrations in any given subsurface environment. It is the purpose of this paper to discuss briefly the present status of the techniques for making such predictions.

GENERAL APPROACH: THE BASIC EQUATIONS

The most often used and probably the most promising of the currently available tools for predicting solute transport in subsurface environments are mathematical models which utilize digital computers. Of these, the ones which now are being very extensively developed are based on adaptations, generalizations, and extensions of an approach which has been used for some time in connection with certain chemical applications, e.g. in chemical engineering and in chromatography (Bird *et al.*, 1960; Helfferich, 1962). The generalizations, extensions and other modifications of the original approach are needed because the systems dealt with in connection with environmental problems are often so much more complex than those met in the chemical applications. For instance, environmental models which cannot handle layered or otherwise nonuniform systems would have little general utility. On the other hand, most of the operational, chemical engineering models assume uniformity of the porous media analyzed.

The especially designed models of solute transport in subsurface layers ordinarily consist of two parts. One part, the waterflow submodel, uses known data in order to compute the water velocities in the subsurface region investigated. The second part, the concentration computing submodel, utilizes these velocities (as well as other known data) to compute the changing concentrations and transfer rates of the solutes of interest. Each one of these submodels is based on a single pair or several pairs of laws, one member of each pair being a mass-conservation law and the other mass-transfer law. One such pair must be written for every transferred* substance of interest. Ordinarily the two members of a pair are combined into a single, basic transfer-equation of the substance in question.

The waterflow submodel referred to above often resembles the groundwater flow models, the use of which is well established in various countries. Such a submodel usually is based on a single basic-transfer equation, the waterflow equation, which shows, for any given small volume of the subsurface (called elementary volume), how the changes in water storage depend upon quantities of water that move in the subsurface and also upon those pumped into or out of the volume in question.† This transfer equation can describe most cases of waterflow in saturated and unsaturated zones. However, in certain cases of flow in the unsaturated zone, the above waterflow equation must be supplemented by an analogous equation for airflow.

The concentration-computing part of the transport model is usually considerably more complex than the waterflow-computing part. The waterflow submodel describes a single, purely physical process involving either a single, mobile system-component (water) or, at most, two mobile, immiscible components (water and air). On the other hand, the concentration-computing submodel may be concerned with many processes, each one of which may involve many, usually miscible, system-components. The processes in question include at least two which are physical in nature: convection, i.e. solute transfer by and with flowing water; and hydrodynamic dispersion, i.e. the mixing between the incoming solutes and those originally present in the pore water. In addition, the submodel under consideration very often must take into account chemical and biological processes. Because of its multiprocess, multicomponent character, a concentration-computing submodel typically contains two or more basic transfer equations. Furthermore, these equations often must be supplemented by additional mathematical relations, which characterize the chemical and biological processes involved.

The basic-transfer equations of the concentration-computing submodel are called transport equations. Two distinct types of such equations are in use.

Subsurface systems affected by relatively slow chemical or biological processes (i.e. processes with rates which are not much larger than those due to convection and dispersion) give rise to transport equations with rate-controlled source of sink expressions.‡ An equation of this type is usually written for the pore space of a given elementary volume of

* In this paper, *transfer* is defined as any directed motion of molecules. In particular, transfer may be due to flow or due to transport. *Transport* is defined as motion of unimolecular or multimolecular particles which is brought about, at least in part, by flow of the surrounding fluid. Transport may be affected by various processes (physical, chemical, or biological) some of which may transform mobile particles into immobile ones or vice versa.

† For those familiar with solute transport modeling the equation in question is stated in the Appendix (equation (1)).

‡ For those familiar with solute transport modeling, the equation in question is stated in the Appendix (equation (2)).

the subsurface. It shows how the mass of a system-component of a given kind (normally a given kind of solute), stored in the pores in question, depends upon three processes: (1) convection; (2) hydrodynamic dispersion; and (3) internal generation (i.e. the chemically or biologically induced transfers of the substance in question from the solid phase of the system into the solution within its pores, or vice versa). As already pointed out, one such equation must be written for each relevant component (solute). A component is relevant either because of direct interest in it or because its concentration influences a solute of interest. The needed transport equations must be supplemented by additional equations describing the so-called rate laws. These laws indicate how the changes in concentration of a given solute, due to a given chemical or biological process, depend upon concentrations of all the relevant solutes and upon other conditions.

Another kind of transport equation is employed in connection with certain subsurface systems with very fast, reversible chemical reactions.* In these systems, the concentration changes due to these reactions take place much faster than those due to convection, dispersion, or molecular diffusion. In such cases, it is convenient to assume for any point within the system that chemical equilibrium is attained there instantaneously, and that this equilibrium may shift continuously as the incoming water flows through the locality in question. Hence, in essence, the reactions of such a system are regarded as equilibrium-controlled. Transport equations with equilibrium-controlled reactions are usually written in such a way that they express the changes taking place in the solids as well as the pore solution of the elementary volume. This has two consequences: (1) such equations do not contain source and sink terms expressing the transfer of molecules from solution to the solid phase or vice versa; (2) in such equations, expressions written for a given system-component and describing a certain change (e.g. change in storage) or a certain effect (e.g. convection effect) may consist of several terms, so that account is taken of all the relevant chemical forms (dissolved or solid) in which this component appears. Transport equations must be supplemented by additional equations. These additional equations describe the chemical equilibria affecting the system component considered. Because of certain features of the equilibrium equations, the equilibrium-controlled reactions give rise to two kinds of concentration-computing submodels, which differ from each other in their mathematical characteristics and hence in their computational procedures. Surface reactions (ion exchange, adsorption) give rise to one of these, while the other arises from "proper" chemical reactions (precipitation-dissolution, oxidation-reduction, complex formation).

NUMERICAL TECHNIQUES

The equations discussed in the preceding section describe how changes in concentration, resulting from various processes, are related to each other. They do not state what actually are the concentrations of interest. The latter information may be derived from such equations, provided that: (1) certain, necessary data about the system in question are available (information about the system parameters, i.e. about the relevant, relatively unchanging system properties; data on the external sources and sinks; and information about initial and boundary conditions of the system); (2) it is known how to utilize the equations in question in order to extract the concentration information needed from the data on hand.

* For those familiar with solute transport modeling, an example of the equation in question is given in the Appendix (equation (3)).

Several ways of accomplishing the latter operation are available—analytical techniques, analog computers, numerical techniques. Under conditions usually met in environmental problems, it seems that only the combined use of numerical techniques and digital computers can provide sufficient generality for routine performance of the task under consideration.

Many numerical methods are known (Berezin and Zhidkov, 1965; Remson *et al.*, 1971; von Rosenberg, 1969). In all of these, the basic transport equations must be approximated by other equations which subsequently are used to write the computer program. Also, note that all numerical methods compute concentrations only for certain discrete points in space. They do this for successive time values, the intervals between these values usually being relatively small. The points in space and time for which computations are made are called grid points, and the intervals between them are called grid intervals. Numerical methods yield concentration values which are approximate. However, by decreasing the size of the grid intervals it is possible, at least theoretically, to increase the accuracy of numerical results as much as one wishes (within the limitations of the conceptual model used and the data available). Use of smaller grid intervals calls for more time-consuming (and hence more expensive) computer calculations. Therefore, the grid intervals required by a given method for attaining a given degree of accuracy may be too small to be practical. Various numerical methods differ in the degree of accuracy they may yield for any particular problem with a given set of grid intervals. They also may differ in computer size and speed requirements, in the degree of mathematical sophistication needed to use them and in other features. Because of such differences and because of the variety of needs the models must satisfy, usually, it is best to select a numerical method for a given type of a problem rather than to try evolving a method applicable to all the expected problems.

The numerical methods used at first in solute transport models have been the so-called finite difference methods. In particular, several types of implicit finite difference methods were employed. For problems in more than one dimension, these involved either the alternating direct implicit (ADI) method (e.g. Bittenger, 1967; Bredehoeft and Pinder, 1972; Rubin, 1968) or the line-successive-over-relaxation method (e.g. Freeze, 1971).

While the finite difference methods performed very satisfactorily in connection with the waterflow submodel, their use in the concentration-computing submodel lead to considerable difficulties, whenever the effects of convection are large in comparison with those of dispersion. These difficulties are caused by the so-called numerical dispersion phenomenon, an artifact which significantly distorts the model's predictions and which results from the nature of approximations made by the difference methods. In an effort to avoid these difficulties, a new numerical technique was developed by modifying appropriately the well-known method of characteristics (Bredehoeft and Pinder, 1972; Reddell and Sunada, 1970). While satisfactory in some cases, this new technique is rather difficult to use on a digital computer, especially for more complex problems. More recently, a highly accurate and efficient (but more difficult to program) method, the so-called Galerkin-finite-element method, has been utilized in connection with transport equations of all types (e.g. Pinder, 1973; Rubin and James, 1973; 1974). It seems that in the foreseeable future this method will be used with increasing frequency whenever the hydrodynamic dispersion effects are small in comparison with the convection effects.

One more numerical method should be mentioned, the so-called method of lines (Berezin and Zhidkov, 1965, pp. 580–607). This method has been employed occasionally for solving solute transport problems primarily because it is part of certain commercially available,

general-purpose, computer programs (e.g. cf. Beck and Frissel, 1973). Utilization of such program makes it easier to tackle problems in question for those who do not wish to prepare a special-purpose computer program. However, it should be pointed out that the efficiency of the method in question often is considerably less even than that of the finite difference methods. Furthermore, it seems that the existing general-purpose programs using the method of lines cannot be used in connection with multidimensional problems without extensive modification.

CURRENT STATE OF SOLUTE TRANSPORT MODELING

The various kinds of solute transport models available will be considered now in the light of the tasks that they are to perform. In order to keep these considerations within reasonable space limits, only what seem to be the more generally needed models will be discussed below.

Thus, it will be taken that the models considered must be able to handle heterogeneous and transient transport systems, i.e. systems with parameters which may vary from place to place and concentrations which may change with time. In addition, such models must be able to take into account hydrodynamic dispersion as well as convective transfer. Lastly, the models in question must involve rather generally applicable expressions for the kind of chemical or biological effects they attempt to reproduce.

On the other hand, treatment of certain relevant, but not generally met circumstances will not be required. For instance, no consideration will be given here to the occasional need for taking into account water density (and hence concentration) induced flows. In other words, it is assumed that the problems to be considered involve relatively small changes in concentration. This is true in most, but by no means all, pollution problems. Another occasionally occurring process to be disregarded here is transport of substances due to mobility of certain solids (e.g. mobile precipitates or colloidally dispersed minerals). Finally, no consideration will be given to the so-called ion-exclusion effects, that is, effects due to repulsion between certain solutes and system particles with the same electric charge (e.g. anions and clay particles). Treatment of some of these cases, neglected here, may be found in the literature (e.g. Bresler, 1973; Reddell and Sunada, 1970). Even after eliminating the above indicated, either especially simple or especially complex conditions, there remains a wide spectrum of circumstances which the transport models under consideration must be capable of handling. Various combinations of such circumstances require either special models or at least special model features.

The more important of such model-determining circumstances, relevant to the waterflow submodel, include various options of the following three factors:

1. The degree of water saturation, the options being full saturation (as met in confined aquifers or water table aquifers), unsaturated state (without or with possibility of significant air trapping) as well as the simultaneous presence of saturated and unsaturated zones.
2. Dimensionality (one-, two-, or three-dimensional transfers).
3. Time dependence (steady or transient, i.e. time-dependent transfer).

The less complicated parts of the existing, digital-computer transport models, the waterflow submodels, can handle any combinations of the above circumstances. Some of these combinations may be treated also by means of existing analog-computer models. However, the digital computer treatment is more versatile. For instance, it can provide more accurate

predictions for water-table aquifers, usually the prime recipients of groundwater pollutants. Furthermore, digital computer techniques are the only ones which can handle adequately waterflow in the unsaturated zone (Rubin, 1966; 1967; Nimah and Hanks, 1974). Such waterflow may have decisive influence upon some of the problems considered. Finally, the most desirable analysis of the environmental problems in question may involve integrated treatment of several terrestrial links of the hydrologic cycle. Recently it has been demonstrated that integrated unsaturated zone-saturated zone, waterflow, digital-computer models (Freeze, 1971; Rubin, 1968) as well as the corresponding surface water-subsurface water models (Freeze, 1972a, b; Pinder and Sauer, 1971) are feasible.

The concentration-computing submodels must be able to handle the circumstances listed above in connection with waterflow modeling. In addition they must consider a large variety of conditions affecting chemical and biological processes, the more important of which involve the following model-determining factors and options:

1. Presence or absence of chemical or biological processes.
2. For chemical reactions: nature of control (rate or equilibrium control), nature of reaction (surface reaction or "proper" chemical reaction), number of reactions involved.
3. For biological processes: number of species or trophic (i.e. food-chain, level) involved.

Concentration-computing submodels are not as yet available for all or even most of the possible combinations of the above circumstances. This fact seriously limits our current solute transport modeling capabilities. The extent of these capabilities is summarized by Table 1. The numbers in this table indicate selected, illustrative references. The letters next to these numbers refer to the numerical technique used. A minus sign within a given subdivision of Table 1 indicates that for the circumstances specified by this subdivision no published model seems to exist. To simplify matters, in preparing Table 1 it was assumed that the dimensionalities of the waterflow and concentration-computing submodels are the same.

Table 1 indicates that there exist, currently, solute transport models for a variety of waterflow conditions. Thus, cases involving saturated as well as unsaturated zones, and steady as well as transient flows can be handled. For the saturated zone, one-dimensional and two-dimensional cases already were treated. Until now, only the former were analyzed for the unsaturated zone. No three-dimensional or saturated–unsaturated transport models are available. Hence these classifications were omitted from the table.

All of the above tractable waterflow conditions can be handled only if the system is not affected by chemical or biological processes. On the other hand, if such effects exist, only more limited waterflow conditions can be accommodated. In fact, only the saturated, one-dimensional, steady-flow cases can be treated for all the chemical and biological circumstances listed in Table 1. In addition, there exist somewhat simplified, saturated-condition models (either neglecting hydrodynamic dispersion or not quite general enough in treating the chemical component) for one- or two-dimensional systems with rate-controlled reactions and: (1) with steady or transient flow but only a single reaction; or (2) with many reactions but only steady flow. Construction of models with mixed reaction systems (e.g. those with some reactions which are rate-controlled and some which are equilibrium-controlled) was not attempted as yet. Hence this classification was omitted from Table 1.

It follows from the above that at present most of the solute-transport systems which can be modeled belong to one of two classes: (1) systems which may have complex waterflow but which are not subject to chemical or biological influences (or at most only one rate-

TABLE 1. The availability of subsurface solute transport models for various sets of subsurface conditions

Chemical and biological effects				Waterflow: Saturated 1D ST	Saturated 1D TR	Saturated 2D ST	Saturated 2D TR	Unsaturated 1D ST	Unsaturated 1D TR	Unsaturated 2D ST	Unsaturated 2D TR
Absent (i.e. solutes are conservative)				←	←	←	7c 30e	←	8d	—	—
Present	Chemical effects alone	rate-controlled reactions	single reaction	↑	←	←	33c*	—	—	—	—
			two or more reactions		—	41d†	—	—	—	—	—
		equilibrium-controlled surface reactions	single reaction		—	—	—	—	—	—	—
			two or more reactions	39e	—	—	—	—	—	—	—
		equilibrium-controlled "proper" reactions	single reaction	↑	—	—	—	—	—	—	—
			two or more reactions	40e	—	—	—	—	—	—	—
	Biological effects alone	rate control, single species or single trophic level		↑	—	—	—	—	—	—	—
		rate control, more than one species or trophic levels			—	—	—	—	—	—	—
	Chemical and biological effects			2*l*	—	—	—	—	—	—	—

c=method of characteristics.
d=finite difference method.
e=Galerkin-finite element method.
l=the method of lines.
*=in the reference, only linear source-sink term was taken into account.
†=in the reference, hydrodynamic dispersion was not taken into account.

D=dimension(s).
ST=steady-state conditions.
TR=transient-state conditions.

controlled chemical reaction); (2) systems with chemical and biological influences but with very simple waterflow.

THE DATA PROBLEM

Availability of a model is a necessary, but not a sufficient condition of predictive capability. The latter condition requires, in addition to an appropriate model, sufficient data about the subsurface system of interest. The data needed for operating a model for any purpose whatsoever were listed above in the section on numerical methods. They pertain to system parameters, external sinks and sources, boundary conditions and initial conditions. Note that all of these, except the last item, may be time dependent.

A solute transport model may be operated for one of two purposes: (1) model verification; (2) transport prediction. A verification procedure tests the reliability of the model by comparing selected indices of system behaviour computed by the model with those observed in the real system. Hence, the model verifying procedure requires historical information which includes appropriate model-operating data (cf. above) as well as data about the past behaviour of the system (e.g. observed changes in pollutant concentration due to placement of known amounts of this pollutant at a known location within the system).

When a model is used for predictive purposes, only appropriate model-operating data are needed. Some of these involve the previously determined, unchangeable system characteristics. The remaining ones are the expected system conditions, e.g. the expected, new sources or sinks; or the expected, new boundary conditions. These new, expected conditions are often the ones which are creating the need for the predictive study in question.

One of the factors which seriously limits the use of solute transport models is the difficulty of obtaining the needed parameter data. These data may be obtained in one of two ways. They may be obtained by means of especially designed experiments, conducted either in the field or in the laboratory. An aquifer field-test is an example of such an experiment. It yields the relevant data on waterflow parameters of the saturated zone. Another example of such an experiment is a laboratory test during which an undisturbed soil-core is leached with a solution containing the pollutant of interest. In such a test, the changing pollutant concentrations in the core's effluent are monitored. From the information thus obtained one may compute some of the necessary chemical parameters. Note that special-experiment laboratory methods of parameter determination usually involve more or less disturbed and very small parts of the system studied. Portions in the corresponding field methods ordinarily are less disturbed and somewhat larger (though still small in comparison with the size of the system). Disturbance of the relevant field conditions and the relatively small sample size are responsible for the main limitations of the experiment-based methods. On the other hand, note that the mathematical computations required by these methods are relatively simple and that the values obtained with their aid reflect rather accurately the actual conditions existing in the segment of the system tested.

The second, more recent and as yet imperfectly developed way of obtaining parametric data involves large parts of the system investigated or sometimes even the system as a whole. It uses system-behaviour data which are similar to those needed in connection with model verification. The method in question employs special procedures which, utilizing the system's model, obtain the "best fit" set of parameters (that is, a set which, when it is substituted into the model, yields predictions resembling as much as possible the observed system behaviour). The oldest of such procedures involves a simple, rather arbitrary and subjective trial-and-error search. More recent and more promising procedures employ special, objective, mathematical optimization methods, sometimes called inverse-problem methods. Some of these employ optimum search methods, others solve the problem directly. Note that the system-behaviour methods for parameter determination may require prolonged and sometimes rather sophisticated computations. Note also that inherent in multi-parameter inverse problems (especially in those using imperfect system-behaviour data) is the possible presence of parameter errors which compensate for each other. Such compensating errors may result in significant inaccuracies.

Table 2 summarizes the current status of the various available parameter-determination methods. As in Table 1, the numbers appearing in Table 2 represent illustrative references. It is clear from this Table that the main deficiencies involve parameter determination for

TABLE 2. Availability of methods for routine determination of transport-model parameters

Parameters for			Methods: Special experiment based — laboratory tests	Methods: Special experiment based — field tests	Methods: System-behaviour based
Waterflow submodel	Saturated zone		+6	+6, 13	≃10, 11, 18
	Unsaturated zone		+6	≃25, 35	—
Concentration-computing submodel	Saturated zone	dispersion	+17	+17	≃10, 33
		chemistry	+20, 23	—	≃33
		biology	≃1	—	—
	Unsaturated zone	dispersion	≃22	—	—
		chemistry	≃24	—	—
		biology	≃12	—	—

+ Available. ≃ Available under limited circumstances. —Unavailable.

the concentration-computing submodel. In this connection, the lack of routine field methods is especially noticeable. Equally serious is the absence of experience with general methods for determining the chemical and biological parameters of the unsaturated zone.

Some of the data needed by certain solute transport models may be difficult or impossible to obtain, because their determination requires introduction into the environment of solutes which are harmful or dangerous. Thus, field tests (which can yield the best parametric data) may be impossible to carry out. It would be even more unrealistic to call for information which can be obtained only by polluting a large part of the system studied. Note that without such data, model verification and system-analysis-based parameter determination are impossible.

In connection with the chemical reaction data it is worth pointing out that for any given mineral assemblage, the chemical parameter data needed in connection with the equilibrium-controlled, "proper" reactions may be independent of location. Thus, it may seem possible to determine such data accurately, once and for all, in the laboratory. Large part of such data have already been collected (e.g. Robie and Waldbaum, 1968). However, the importance of this fact should not be overemphasized. First, it may not be easy to determine the minerals which are to be taken into account. Second, the absence of rate dependence of certain reactions (due to certain local conditions) often will have to be experimentally determined. Thirdly, many of the relevant reactions involve non-crystalline solids for which at present no equilibrium data are available. Because of the above three considerations it may be necessary to carry out special, parameter-determining tests, even in connection with what might prove to be equilibrium-controlled reactions.

DISCUSSION

It has been demonstrated (Tables 1 and 2) that serious deficiencies exist: (1) In the capability of the existing solute-transport models to handle various important environmental conditions; (2) in the capability of the existing parameter-determination methods

to perform under many of those conditions. Such deficiencies are not surprising if it is borne in mind that almost all the efforts to develop quantitative, widely applicable tools for predicting solute-transport in subsurface environments are less than a decade old. The deficiencies in question clearly point out the future research needs.

In view of these deficiencies, our capability to model most of the environmental problems of interest may be questioned. For instance, it may be argued that some of the most important practical problems of interest involve three-dimensional, saturated–unsaturated solute transport for which no concentration-computing submodels are available. Equally serious criticism may be raised in connection with the lack of models involving more complex waterflow conditions coexisting with chemical or biological processes.

However, the situation, though clearly undesirable, may not be as serious as it appears at first sight. The fact is that the currently available models can analyze numerous important solute-transport cases. Furthermore, models required by many of the circumstances as yet not taken into account may not be very difficult to develop. After all, the capability of taking into account, separately, complex waterflow conditions and complex chemical or biological influences has been established. Hence, the task of treating these complexities simultaneously requires extensions and modifications of models which already exist. Usually, it is easier to achieve such extensions than to design entirely new models. As for the lack of three-dimensional treatment, at least for the time being it may be possible to substitute for it a model coupling one-dimensional, vertical transport in the unsaturated zone with two-dimensional, horizontal, saturated zone transport, in a manner similar to that suggested in connection with waterflow (Pikul *et al.*, 1974; see also Konikow and Bredehoeft, 1974).

In fact, it seems that the most serious obstacle to be faced in connection with tackling more complex conditions (either by ad hoc, approximate model adaptations or by more exact model applicability extensions) probably will be due to the fact that such developments create great demands as far as computer size and computation time are concerned. Due to this fact, today it is even difficult to tackle on the computer large, complex three-dimensional, saturated–unsaturated problems which involve waterflow alone. The corresponding difficulties of handling comparable solute transport systems could be much greater. Hence, many of the more accurate models of really complex transport systems may require more efficient computers or more efficient numerical techniques than those available at present.

The problems of parameter determination and model verification seem to be more serious than the problems of model-construction, especially due to the already mentioned difficulties of getting field data for systems in which the expected pollution has not occurred as yet. Parameter determination for such systems will have to depend largely on laboratory tests. In addition, it might not be possible to verify these models before reaching practical decisions with their aid. Because of uncertainties involved in relying on laboratory tests and on unverified models, if such decisions are reached and if they result in introduction of pollutants into the environment, special precautions are imperative. They should include appropriate monitoring of the system and the utilization of the obtained data for periodic model verifications. An attempt should be made to reach satisfactory verification long before the solutes in question reach harmful concentrations.

The solute transport models discussed so far may be quite useful in connection with short- and long-range utilization of land-based, waste-disposal systems. Trustworthy models of this kind can help in assessing the subsurface effects, in locating the sites and in the

design or management planning of such systems. In particular, the models in question can help to determine whether the natural, solute-dispersing (i.e. mixing and diluting), and pollutant-degrading properties of a given site and of its immediate surroundings can prevent undesirable contamination of actual or potential water resources, even in the presence, at the soil surface, of uninterrupted, unlimited-duration input of a pollutant of a given concentration. In such cases, from a long-range point of view, the third factor often utilized to decrease pollution effects, the pollutant-fixing capability, usually cannot be relied upon, because ultimately it will become exhausted, either for chemical or for biological reasons. Alternatively, the subsurface may clog before such exhaustion occurs and the site will be rendered useless. Note that under the circumstances considered, degradation which produces immobile products eventually also must result in clogging.

If, for any given site, it is found that unlimited-duration, uninterrupted input of a pollutant will result in contamination of a water resource, an appropriate solute-transport model may help to discover special management measures which will make it possible to prevent such contamination. For instance, the model may show that an intermittent pollutant input can achieve the above end though such an input will be of unlimited duration. Note that with a pollutant subject to reversible, pollutant-fixing chemical reactions or other reversible processes, such a measure can utilize the fixing properties of the subsurface, which, from a long-range point of view, were ineffective when pollutant input was continuous.

In addition, the model in question can help in testing the effectiveness of decreasing the relevant input concentrations. Finally, model-based computations may reveal the effects of artificially increasing waterflow rates, of inducing water unsaturation or of otherwise modifying the waterflow conditions.

Occasionally it may be possible to test experimentally the effectiveness of site properties or measures discussed above at the intended disposal site itself. The results obtained from such tests most probably will be more accurate than those obtained from mathematical models. However, the large number of the properties and measures which should be thus tested may render experimental procedures uneconomical or even impossible, especially if the tests must be of long duration.

The use of experimental approach in connection with contamination due to nonpoint, areal sources is usually outright impossible. However, under such conditions, the practicability of models may also be questioned, primarily because of the difficulties in obtaining the relevant parameter and boundary-condition data. While those difficulties are undoubtedly real, it seems that under such circumstances, judicial application of the "worst-case" and stochastic inputs to the models in question will yield significant and helpful results.

The usefulness of the models discussed in this paper for making geographically broad, "global" predictions may seem rather limited. Ordinarily, to make such predictions, the rates of the numerous, relevant, location-dependent processes are lumped into overall, "global" rates without considering the effects of actual parameter distribution in space (as it is done in the solute transport models). It seems that in connection with such lumping, it is worth discussing at least two considerations which may involve the use of the models described in this paper. First, clearly, the locations of waste-disposal sites should, can, and increasingly will be optimized. The models presented here may help in assessing the long-range "global" effects and the limits of such an optimization. Secondly, a disposal site which is ineffective from a long-range point of view may, under certain circumstances, be used for a limited period of time without creating a danger of contamination. Sites of this

kind would not solve the long-range disposal problems, but could delay the need of facing them for a finite period. During such a period, technological developments of one kind or another might solve the disposal problem in an economic manner which does not require further waste deposition in the subsurface. Solute transport models could reveal for various pollutants the possibilities inherent in such planned delays. Dynamic "global" models which take into account technological developments would have to consider the effects of the delays in question.

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APPENDIX

Commonly Used Basic Transfer Equations

I. *Water transfer (waterflow) equations*

$$C\frac{\partial H}{\partial t} = \operatorname{div}(K \cdot \operatorname{grad} H) + S_w \tag{1}$$

where x and y are horizontal space coordinates and z is the vertical space coordinate; t=time; $H=h+z$ hydraulic head; h=pressure head; $C=C(x,y,z,h)$=specific storage or differential water capacity; $K=K(x,y,z)$=hydraulic conductivity (scalar or tensor); $S_w=S_w(x,y,z,t)$=source/sink function for water. In the unsaturated zone, K as well as w (=water content) are functions of h.

II. *Transport equations*

1. Transport affected by rate-controlled processes.

$$\frac{\partial}{\partial t}(wc_i) + \operatorname{div}(qc_i) = \operatorname{div}(D \cdot \operatorname{grad} c_i) + \sum_{j=1}^{J} S_{ij} \tag{2}$$

where t and w were defined above; c_i=concentration of the ith ion; $q=-K \cdot \operatorname{grad} H$; D=dispersion tensor; S_{ij}, with $j=1, 2, \ldots, J$, are the rate laws for the J processes affecting concentrations c_i.

2. Transport affected only by a single, equilibrium-controlled reaction in which two solutes, $i=1$ and $i=2$, combine reversibly to form a single, immobile product.

$$\frac{\partial}{\partial t}(wc_i) + \frac{\partial}{\partial t}(w\bar{c}_i) + \operatorname{div}(qc_i) = \operatorname{div}(D \cdot \operatorname{grad} c_i); \qquad i = 1, 2 \tag{3}$$

where $\bar{c}_i$=concentration of ion i within the immobile phase; and all other variables are as defined above.

Note: The variables and parameters of equations (1), (2), and (3) are expressed in any consistent system of units.

AN 8000-TON-A-DAY RECOVERY SYSTEM

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We have a solid-waste prototype program in St. Louis and if anyone has any questions about this prototype program, you can see me before the end of the conference and I can answer your questions then. What I would like to describe now, in a briefer period, is a system we are now under design with and have already purchased some equipment for.

On February 28 of this year, Union Electric Company announced plans for the development of a solid-waste utilization system capable of handling essentially all of the solid waste generated in the St. Louis, Missouri region. The St. Louis area covers 4500 square miles and includes about 2½ million people. The system is scheduled for full-scale operation by mid-1977. The St. Louis area also includes over 200 governmental units. Union Electric is a private electric utility. We will design, we will build and operate the system without financial assistance from any governmental unit. We fully expect the system to provide a profit.

Under the plan, Union Electric will establish and operate five to seven strategically located solid-waste collection transfer centres capable of handling 8000 tons per day, 6 days per week, for a total of 2½ to 3 million tons of waste annually. Refuse will be received from private and public trash haulers at these centers and transferred by 100 yd^3 closed containers for rail shipment to processing facilities at Union Electric's Meramec and Labadie power plants. Refuse will also be received from the haulers at these two plants.

Meramec plant includes two 125,000-kW Combustion Engineering pulverized-coal boilers, a 270,000-kW Foster Wheeler pulverized-coal boiler and a 300,000-kW Foster Wheeler boiler. All four units will be equipped to burn processed waste at a rate equal to 20% of the boilers' full load heat input requirement. The Labadie plant includes four identical 600,000-kW Combustion Engineering tangentially fired pulverized-coal steam electric generating units. All four units will be equipped to burn processed waste.

The two plants—Meramec and Labadie—will provide a refuse-burning capacity of 16,000 tons per day, which is twice that generated in the area. The raw waste, including household waste, appliances, commercial waste, demolition lumber, and selected industrial solid and liquid wastes, will be received by both power plants by rail. Two stages of hammermilling will reduce the solid waste to a particle size of 1 inch or smaller. Following air classification, the burnable fraction will be pneumatically transported to the waste-firing burners in the boiler furnaces. Redundancy is designed into all stages of the process to ensure availability of waste-processing facilities at all times at each plant. The heavy fraction from the process air classifiers will be separated into organic, glass, magnetic, and non-magnetic metal

fractions. The organics will be returned to the hammermills for further size reduction and ultimate transfer to the burnable fractions which will preclude the need to dispose of these materials in landfill. Magnetic and non-magnetic metals will be recovered and recycled. Glass will be recycled if suitable separation techniques and markets can be developed. We are prepared to landfill the glass and unfortunately in the St. Louis area we have a very good grade of silica and there is just no market for the glass locally.

Relative to the economics: the capital cost is estimated to be $70 million for an 8000-ton-a-day capacity system. The annual operating costs are estimated at $11 million. Now those numbers were generated 6 months ago. They include 10% per year escalation and a 20% contingency allowance. In order to amortize the capital and operating costs, we will receive revenue from fees charged to the private and public trash haulers, from revenue received from the sale of ferrous and non-ferrous metals, and from savings in coal fuel costs.

Union Electric does not suggest that our solid-waste utilization system is the only practical solution to solid-waste problems. There are other systems that may well be technically and financially more attractive. However, for St. Louis, the problem of incinerator and landfilling of solid-waste disposal and the attendant air and water pollution and land degradation, we hope, will be superseded with the opportunity to develop the solid wastes for society's benefit by recycling ferrous materials and conserving limited natural resources.

I would just like to say a word about the environmental effects. We ran a series of gas emission tests with the prototype system late in 1973. There was a slight reduction in the performance of the electrostatic precipitators, approximately 1½ percentage point reduction in the precipitator efficiency. After we ran our tests, the U.S. Environmental Protection Agency was given the boiler for 2 weeks. They ran a series of gas emission tests. They also looked for SOx, NOx, CO, CO_2 and HCl and, in their view, there is nothing in the gas stream that would be environmentally detrimental. They also looked for mercury vapor and could detect none. Because of the inconclusive nature of these tests, Union Electric will begin a series of 6 weeks of testing of particulate emissions only. So as to characterize those emissions and in particular to characterize the performance of the electro-static precipitators when they are firing this new combination of the heterogeneous fuel.

The bottom ash from the furnaces is pumped with Mississippi River water to a settling pond. Of course that water finally finds its way back into the Mississippi River after it has carried this combination of coal and solid waste ash. We have a continuous monitoring program on the ash pond. We have taken a series of tests, including sixty-four parameters, and we have found no detrimental water effects—except for some degradation of the oxygen levels. We are fairly certain that except for oxygen level, we will not have any detrimental water effects.

If any of you would like additional information on this process, including all the environmental data, if you would either give me your card or name and address, I will mail you a package of material on the process as soon as I get back to the States.

THE SEPARATION OF DOMESTIC REFUSE BY AIR-SEPARATION METHODS

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Abstract. Domestic waste contains $\pm$25–30% of waste paper. If separation of this waste were possible in a usable quality, it would mean a welcome supply to the material stock of the Dutch paper industry.

After a literature study, TNO started the development of a process concerning dry separation of domestic waste in various components. The results show that a usable product at an acceptable price can be obtained.

Experiments with a plant upon a semi-industrial scale, capacity 1 t/h domestic waste, are in an advanced phase. The construction of a 10 t/h pilot plant is considered briefly.

INTRODUCTION

Cellulose is a most important raw material for the paper industry. It is recovered from wood and straw and, increasingly, from waste paper, by collection. It is estimated that there is a rapidly increasing shortage of cellulose in the paper industry. However, domestic waste still contains $\pm$25 or 30% paper, in spite of waste-paper collection.

If paper separation from domestic waste could be realized, a considerable quantity of raw material for the paper industry would become available. Moreover, a substantial reduction of waste processing would result. For these reasons, TNO commenced research concerning the possibilities of process recovery of paper from Dutch domestic waste, and also concerning the quantity, quality, and price of the recovered raw material.

This experiment has been in operation since 1971 and consists of:

1. study of literature,
2. informative research on a small scale,
3. design, construction, and testing of a pilot plant with a capacity of 1 t/h,
4. design of a 10 t/h plant.

The research is now in phase 4.

Below appears a report of some results. The experiment is supported by a Dutch construction company. The Institute for Waste Disposal SVA, because of the interest shown by them in this subject, also contribute to the experiment.

If technically a positive result is reached, the Institute will [illegible] economically the separation system as part of a complete system for [illegible] was[illegible]

LITERATURE STUDY

Literature study and personal inquiry showed that in America numerous experiments are being made concerning the development of process-separation of domestic waste paper.

SEPARATION SYSTEMS

The separation systems mentioned in the literature are divisible into two groups: separation of fibres after mixing up domestic waste with water, separation without water addition.

A wet separation system is at present being developed by the Black Clawson Co. They have constructed a semi-industrial plant at Franklin, Ohio, U.S.A., the operation of which is based on the paper production process. Instead of cellulose, however, the pulper is fed with domestic waste. Of course, the greater part of the waste is unusable and has to be drained. A disadvantage, however, is the difficult processing of these wet waste residues. Moreover, a large quantity of wastewater has to be disposed of. The dry separation systems in development are based on separation by means of air separators, ballistics, screens or a combination of some of these.

Piloting is proceeding, for example, at

Stanford University, U.S.A.
Bureau of Mines, Pittsburgh
Forest Products Laboratory, Madison, U.S.A.
Franklin Institute, Philadelphia, U.S.A.

It is concluded from available information that in the Netherlands the "dry-system", both environmentally and economically, has good prospects. American domestic waste differs completely from Dutch waste, containing, for instance, almost twice as much paper as the Dutch. Ample examination of dry separation methods with normal Dutch domestic waste seems to be desirable.

UTILITY OF SEPARATED PAPER FIBRE PRODUCT

It is important for the paper manufacturer to be sure when using this paper fibre that the cost of the manufacturing process is not increased by technical troubles or slowing of the paper machinery. Moreover, he is concerned about a suitable quality of the final product. The product has to be judged on properties such as tearing and tensile strength, sizing, filler retention, etc. Until now the only figures published in literature concerning recovered waste paper are related to fibre strength. They are mentioned in Fig. 1, showing the strength in scale from 10 up to 100. On the left are woodpulps, on the right are recovered pulps from waste products. According to Van Staa and McKee, in many aspects use of recovered fibres is preferable. They assume an improved quality of the final product to that of a "virgin" material *qua* tearing strength, dimensional stability, curl tendency, opacity, shot-out resistance, thickening, sizing, nature of surface and filler retention and properties such as crack- and tensile-strength.

It is clear that only experiments can settle the questions concerning the utility of recovered fibres, and on such a scale that a satisfactory quantity of raw material is available in order

to manufacture representative paper samples. Meanwhile the Dutch paper industry is willing to initiate a test-production with the recovered waste paper raw material.

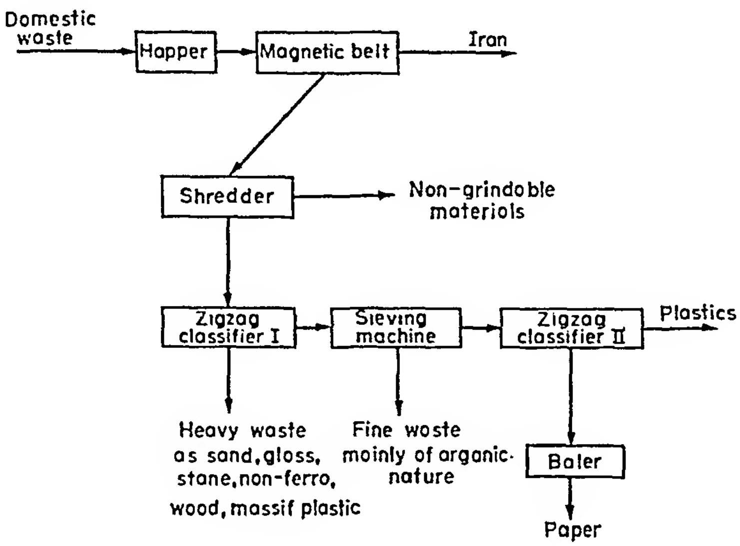

Fig. 1. Principal scheme of the TNO domestic waste-separation system. Domestic waste—bunker—magnetic conveyor—ferrous metal-hammermill—ungrindables—zigzag air classifier I—screener-zigzag II—plastics—heavy material such as sand, glass, stones, non-ferrous, wood, solid plastic—fine waste, mainly organics—paper—baling press. Material to be processed.

PRINCIPLE OF THE TNO SEPARATION SYSTEM

Based upon the present know-how of separation techniques, completed with data of the literature, TNO tested the possibilities of achieving a dry system for domestic waste.

During the separation of the mixture containing different materials found in domestic waste the differences of physical properties of these materials (magnetism, velocity, intensity, and particle size) are utilized. This system is shown in Fig. 1. Primary separation of paper and residue waste is possible by reducing the waste into pieces of +10 cm. Paper requires a different velocity for reduction than do the remaining waste components. Separation by velocity is carried out in a zigzag classifier (Fig. 2). The mixture to be separated by velocity is conducted into a vertical channel, provided with a number of bends. Air is blown up at a constant speed. Small particles (F) are taken by the air current, heavy particles (G) fall down along the wall. At the bend the heavy waste crosses the air current, causing a further separation. The extent of separation can be raised by using further channel units (compare the dishes of a fractionate column).

When supplying ground waste to a suitably sized classifier, paper leaves the top of the classifier carried by the air current. This paper component still contains plastic films and fine waste. By screening and sifting, a paper product is obtained which offers possibilities for raw material for the paper industry.

Figure 3 shows a provisional plant scheme for the separation of waste and tin cans from domestic waste, preconnected to an incinerator. In this scheme the sacks are first torn, followed by separation and grinding of waste. The next phase is from the mill and sifting,

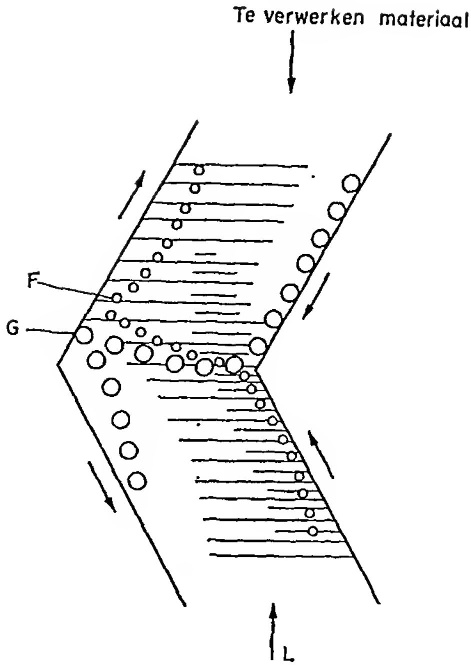

Fig. 2. Principle of zigzag air-classifying (L=air current, F=light particles, G=heavy particles).

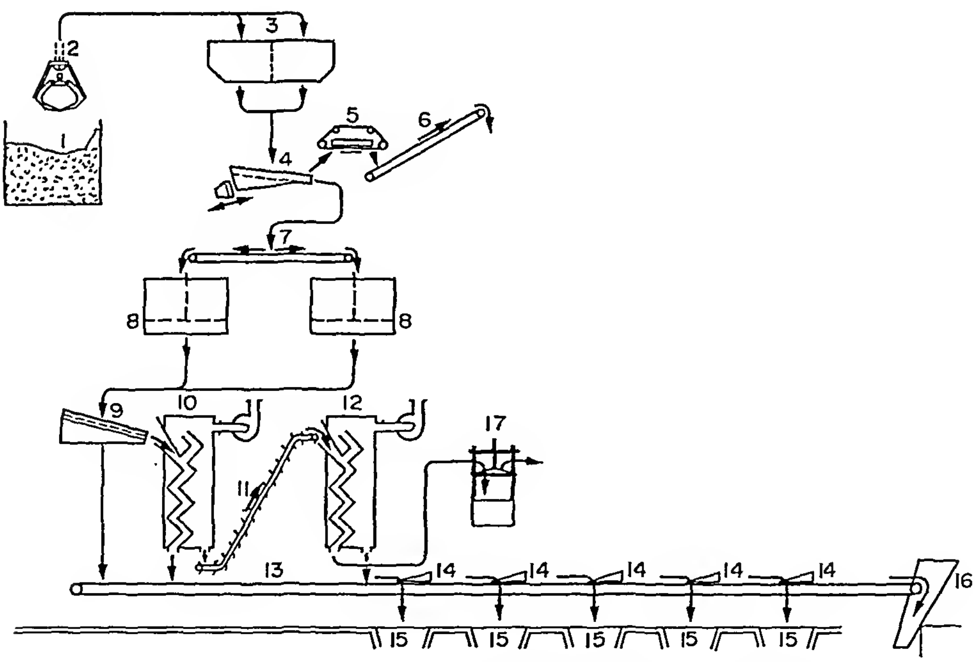

Fig. 3. Scheme for separation of paper and tin cans out of domestic waste.
(1) Bunker, (2) poly-grab, (3) sack-tearing machine, (4) vibratory feeder, (5) magnetic separator, (6) belt conveyor for iron and tin cans, (7) feeding conveyor for shredders, (8) shredders, (9) vibrating screen, (10) classifier-stage I, (11) transport-stage I up to stage II if any, (12) classifier-stage II, (13) outlet conveyor—(a) siftings vibration screen, (b) residues classifiers I and II, (14) strippers on conveyor (13), (15) hoppers incinerator, (16) outlet (1) to bunker, (17) baling press.

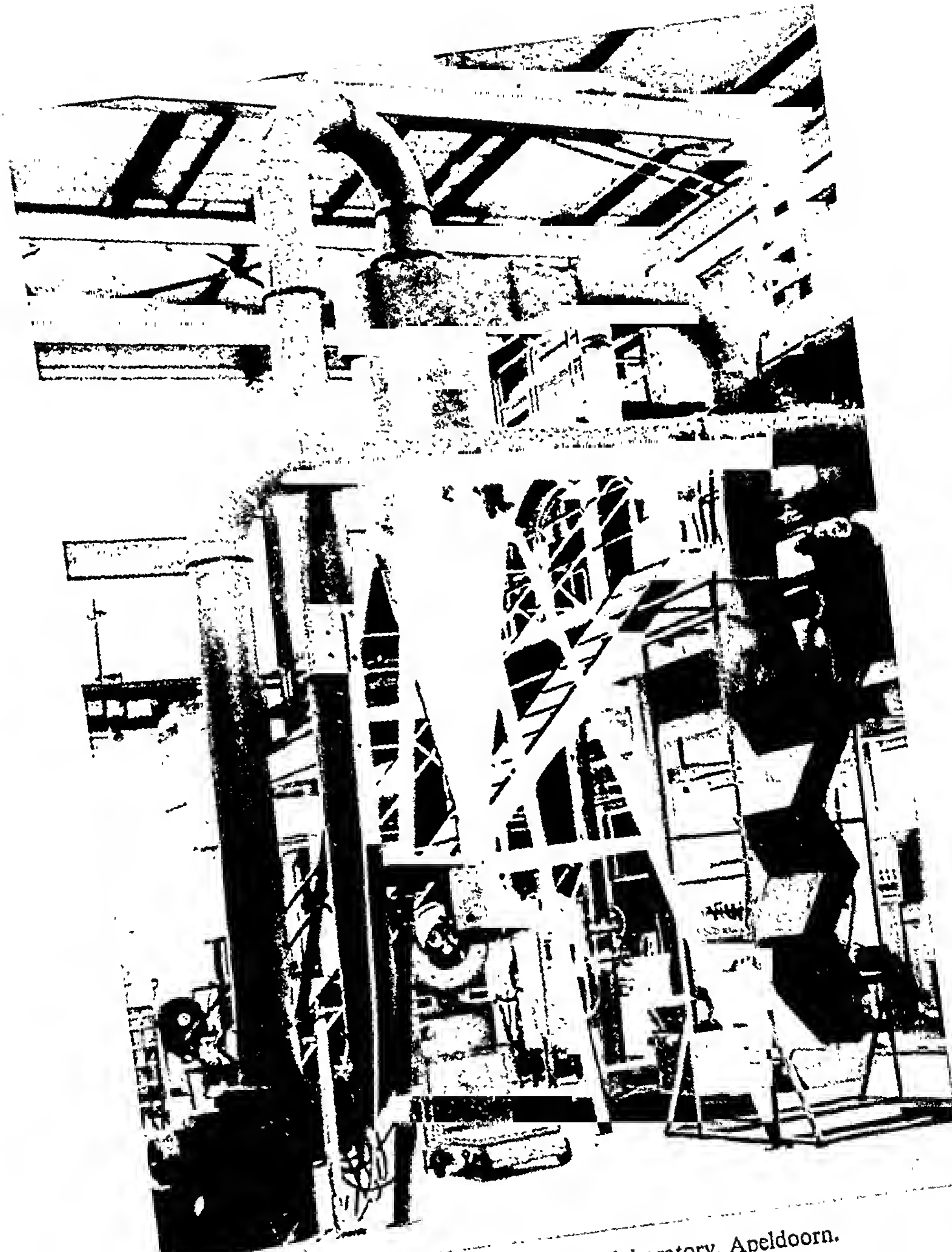

Fig. 4 Zigzag classifier in TNO laboratory, Apeldoorn.

screening, and second sifting. Then five products are obtained, namely tin cans, paper, plastic films, fine organic material, and heavy residue. The unusable products are disposed of by controlled tipping, composting, or incinerating.

GRADE OF DEVELOPMENT OF THE TNO SYSTEM

In 1972 a pre-examination upon a laboratory scale was undertaken by the Central Technical Institute TNO. By means of a plant with a capacity of 100 kg/h domestic waste a paper product was separated and the Fibre Institute produced experimental paper sheets. The cardboard industry considered the quality of the fibres usable for production. The experiment went on by designing and constructing a plant with a waste capacity of 1 t/h. The first phase of this plant (Fig. 4) has been tested and is ready for use. In connection with cost, grinding was undertaken by the mill of the Municipal Waste Disposal Plant at Haarlem. It was estimated in April 1974 that a complete plant at Haarlem produced in a long-run test a sufficient quantity of paper raw material to enable the cardboard industry to carry out test productions. Then more exact data concerning the calculation of investments and operating costs will be collected. When the results of this long run are satisfied, the next phase of development will consist of designing and constructing a plant with a capacity of 10 t/h domestic waste. Preparations for this are already going on.

DISCUSSION

MOSER: Permettez-moi, Messieurs, d'attirer votre attention sur un principe à observer dans toutes les questions de recyclage. Le représentant du Japon vient de citer l'exemple du papier dont, dit-il, le recyclage entraine und réduction de la pollution, c'est-à-dire une réduction des charges imposées à l'environnement. Je crois qu'il n'existe pas de solution générale pour aucun des secteurs du recyclage; il faut, dans chaque cas particulier, examiner de très près chaque détail.

Pour ce qui est du papier, le problème est encore en discussion et les opinions divergent. Est-il plus avantageux pour l'environnement d'incinérer le papier ou de le recycler? Nous devons penser à l'avenir. Il y a aujourd'hui de grandes installations d'incinération où l'on produit de la chaleur, c'est-à-dire de l'énergie. Cette énergie est utilisée pour chauffer de grands centres d'habitation; cela permet de réduire les émissions de SO_2 produites par le chauffage ordinaire, ce qui représente une forte diminution des charges imposées à l'environnement. D'un autre côté, si nous recyclons le papier, nous économisons de l'énergie au niveau de la fabrication, ainsi qu'à celui des ressources naturelles.

Il est très important pour l'avenir d'arriver à une quantification écologique de tous les problèmes, pas seulement jusqu'au premier stade, mais plus loin encore. Aujourd'hui nous avons déjà des usines d'incinération qui, en plus d'une installation pour la production de la chaleur, sont équipées d'un système de récupération des scories qu'on peut utiliser comme matériau de construction routière. On peut alors dire qu'il s'agit là d'un recyclage presque complet.

HERBERT: I will very briefly summarize a very lengthy paper that I've brought with me. I would like to discuss briefly a wet system which accomplishes the same things as the two systems that you just heard. The system was originally designed to recover everything that is recoverable in mixed municipal refuse and to leave as small a residue as possible—this being the Number One environmental purpose of the plant, to essentially reduce the landfill to almost nothing and that what went to the landfill would be an inert residue. I would like to point out here since this is a multi-national meeting, that you only recover those items for which markets exist—and please, we must all remember that, it seems very obvious—so many people have gone in and established reclamation centers for things for which no market existed. Hence you must have a modular system so that you can pick out those things that you want. In this, I might add that this particular system has been mentioned several times in the meeting before. It was mentioned as Franklin, Ohio, it was mentioned as the hydropulping system, and as the wet pulping system. In essence, the material is pulped in the machine of which you just saw a picture. There are 1-inch openings in the bottom of it and a slurry is withdrawn. The slurry contains the plastics, the yard waste, the paper, the food waste—most of that material—plus the glass, the aluminum, copper, and all the other goodies such as coins that are thrown away. The very first step is to put it through a liquid classifier, a cyclone type which separates heavy material from light. The heavy material is drawn off the bottom and it is washed, right in the classifier, and then conveyed to a mineral recovery system which will be discussed a little later.

The light material is then pumped to a tank, where it is thoroughly mixed. If a market exists for paper fiber, it is pumped over to a paper recovery system, where, through a series of screens and cleaners, about 50% of the paper that is in the system is recovered. This is actually done at Franklin, Ohio, and the recovered fiber is pumped over to an adjoining paper mill. If there is no market for it, then you burn all of the organics.

I might digress here for a minute to discuss an environmental aspect. The question was raised this morning, when should you burn paper fiber and when should you recover it? The answer is, you recover it if a viable market exists for it. But an important point that no one has made yet in this meeting is: Cellulose, and cellulostic materials such as food, are the only renewable source of energy we have on this earth. They take the CO_2 out of the air and they take the heat from the sun, and they make growing things that we can use and we can derive energy from at a later date. So, when you hear a lot of these little old ladies in tennis shoes crying because we're chopping down trees, let's remember, this is a very, very, valuable energy source for this whole world—not just for the United States, and not just for France.

I have about 3 minutes here. In the particular system we are working with, we have borrowed extensively from the pulp and paper industry, which is the industry in which my company has been involved for a little over 100 years. If there is, in the neighborhood of your particular plant, a Union Electric Company that has large boilers equipped to burn this type of fuel, then this would be the end of the process. We would de-water it after the mixing and ship it over to the boiler house. In the areas in which we have been involved, all of the large utilities and all of the large powerhouses are set up to burn either oil or gas. As such, they cannot use a fuel which contains up to 10% by weight of ash on an oven-dry basis without contaminating the air. They just do not have the electrostatic precipitator capacity.

So in the areas in which we are involved, we will be installing our own boilers and these will again be borrowed from the paper mills. They will be boilers that have been used for years to burn bark. And they work very well. In some instances we've been going all the way to generating electricity with turbogenerators. This adds tremendously to the capital cost of a plant. But it has to be done and with today's high fuel costs, the amount of money for which you can sell your energy is very substantial.

One other item is still under development, it is to take the fuel developed from this wet system—which, I might add, averages 50% moisture, but it is extremely uniform. It only varies from about 49 to 51%. It has a very constant BTU value.—You dry down to about 25% moisture and then pelletize it. Then it becomes a highly storable, very easily handled material. The dry shredded and the wet shredded material in bulk form is extremely difficult to handle in material handling systems. When you pelletize it, you can transport it because it is now densified. There are some very good indications that it can be blended with the coal and then ground up right in the pulverizers. You can do your blending right at your coal-storage plant. The boiler people tell us that you probably can burn up to 40% by weight of this pelletized material.

The net result is that through systems properly designed, you have no adverse effects upon the environment. Even though this is a wet system, unless you have fiber recovery, 100% of your water is recycled, so there is no water effluent from the plant. There are no odors in the plant, because if you have your own boilerhouse, you draw the air from your tipping area, which does have an odor, and use that for the primary air in your boilers. You design your plant to take care of the noise problem. You have to put up a good building. You can't put up a little steel shack. It must be architecturally attractive to the community. If you design your electrostatic precipitators properly, you're well within the guidelines for particulate emission. I have one more minute. I think I would simply sum up by saying that both the wet systems and the dry systems do an almost identical job. There are advantages to one and advantages to the other. As we say back home, you pays your money and you takes your choice. Thank you very much.

JOY: On the original program, I did have Mr. Ross to speak but if he will accept my apologies I would like to move directly onto Mr. Van Wambeke, because this is a change into atmospheric pollution, and if we have time, I would like Mr. Ross to try to say something on the handling and processing plants at the end. But I think I would like to take the air-pollution side of the problem right now.

PERSPECTIVES DES MÉTAUX DU GROUPE DU PLATINE DANS LA LUTTE ANTIPOLLUTION*

L. VAN WAMBEKE

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Les métaux du groupe du platine et en particulier le platine et le palladium qui interviennent pour environ 90% dans la consommation du monde occidental ont d'importantes applications industrielles en dehors de leur utilisation extensive en joaillerie et plus récemment à des fins spéculatives. Les applications de ces métaux reposent sur une série de propriétés dont les principales sont la résistance à la corrosion à température élevée, la conductivité électrique et les excellentes propriétés catalytiques largement utilisées dans certaines réactions chimiques essentielles pour l'industrie. Les principaux secteurs industriels de consommation des métaux du groupe du platine (MGP), en l'occurrence principalement le palladium et le platine sont les industries chimique, pétrolière électrique, la verrerie, l'art dentaire et la médecine. Aux Etats Unis où il existe des statistiques précises sur l'utilisation des différents MGP par secteurs industriels, le palladium intervenait pour 56% et le platine pour 35% dans la consommation en 1972.**

L'augmentation substantielle de la production minière mondiale de MGP qui est passée de 39,6 T en 1960 à 140,5 T en 1972 reflète bien l'accroissement appréciable de la demande de ces métaux et en particulier du platine et du palladium bien que la production secondaire soit importante. La consommation du monde occidental pour le platine a doublé entre 1960 et 1970 pour atteindre environ 44 t et s'est encore considérablement accrue depuis 1972 68,4 T en 1972 et 77,5 T en 1973 suite non seulement à des achats massifs du Japon pour des usages non industriels mais aussi à une augmentation appréciable de la demande dans les secteurs industriels classiques.

La consommation dans les secteurs industriels est en effet passée de 36,3 T en 1970 à environ 46,7 T en 1973 pour le platine uniquement. Le Tableau 1 donne la distribution de la consommation de platine par secteurs industriels en 1969 et 1973.

La consommation de palladium du monde occidental serait du même ordre de grandeur ou même plutôt légèrement supérieure à celle du platine si l'on se base sur les données statistiques existantes publiées par l'US Bureau of Mines. Le taux annuel d'accroissement de la consommation de MGP est le plus élevé parmi les matières premières minérales. Bien que l'on ne dispose pas de données sur la production secondaire, celle-ci ne contribue que pour 15 à 25% de la consommation de MGP du monde occidental à cause du taux très élevé d'accroissement de la consommation. Il faut aussi noter que la substitution du MGP reste limitée dans la plupart des applications.

* Texte presenté en 1974, revu en décembre 1976

** U.S. Bureàu of Mines, 1972: *Minerals Yearbook*, Vol. I.

TABLEAU 1. Distribution de la consommation de platine par secteurs indistriels en 1969 et 1973 (en tonnes métriques)

Secteurs industriels	Japon		U.S.A.		Europe		Autres		Total monde occidental		% consommation	
	1969	1973	1969	1973	1969	1973	1969	1973	1969	1973	1969	1973
Joaillerie Décoration	4,23	28,00	1,12	0,62	1,46	1,55	0,47	0,63	7,28	30,80	17	40
Chimie	0,31	1,21	5,44	7,44	3,98	4,20	0,31	0,22	10,04	13,07	23	17
Pétrole	0,40	1,49	2,30	4,39	2,83	3,11	1,31	1,06	6,84	10,05	11	13
Verres	1,09	3,11	1,96	2,27	2,08	1,87	0,03	0,03	5,16	7,28	12	9
Electricité	0,59	3,11	3,52	3,11	3,17	2,33	0,56	0,63	7,84	9,18	18	12
Art dentaire Médecine	0,16	0,62	0,68	0,56	0,56	0,56	0,16	0,16	1,56	1,90	4	2
Divers	0,22	1,34	1,49	1,65	2,21	1,96	0,25	0,25	4,17	5,20	10	7
Total	7,00	38,88	16,51	20,04	16,29	15,58	3,09	2,98	42,89	77,48		

Récemment les MGP, en l'occurrence surtout le platine et le palladium, ont trouvé une série de nouvelles applications dans les secteurs suivants:
— l'industrie automobile,
— le traitement des eaux polluées,
— le traitement du cancer,
— les piles à combustibles,
— l'énergie nucléaire (eaux de refroidissement).

Cependant le principal nouveau secteur de consommation à court et moyen terme est sans aucun doute l'industrie automobile et concerne surtout le platine et le palladium. Déjà en décembre 1973, la General Motor aux Etats Unis a sorti ses premières voitures à convertisseurs catalytiques Pt/Pd. Cette nouvelle application aura un impact important sur l'amélioration de la qualité de l'air et aussi sur la production minière du MGP. J'analyserai brièvement ces deux points:

1. LE PROBLÈME DE LA POLLUTION DE L'AIR DUE A LA CIRCULATION AUTOMOBILE

Ce problème qui préoccupe de nombreux gouvernements a pris une ampleur internationale. Les principaux gaz polluants émis par les automobiles sont l'oxyde de carbone (CO), les hydrocarbures non brûlés (HC) et les oxydes d'azote (NO_x). La contribution des gaz d'échappement à la pollution de l'air dans la Communauté européenne atteint 90% pour le CO, 60 à 70% pour les HC et 40 à 45% pour les NO_x. Il faut y ajouter le plomb qui est émis sous forme de particules solides (oxyde de Pb surtout) et intervient pour environ 90% dans la pollution de l'air par ce métal. Les polluants gazeux émis par les véhicules à moteurs ont été responsables localement des brouillards photochimiques nuisibles aux voies respiratoires. Toutes ces substances polluantes émises sont nocives à divers degrés pour l'homme et les législations nationales tendent à réduire actuellement à un minimum le niveau des émissions par la technologie compte tenu d'un coût acceptable. Les problèmes consistent donc outre l'élimination du plomb tétraéthyl dans l'essence à transformer en majeure partie hydrocarbures (HC) et l'oxyde de carbone (CO) en vapeur d'eau et en

dioxyde de carbone par oxydation et de réduire les oxydes d'azote en azote. Il est évident que les conditions qui favorisent l'oxydation rendent les réactions de réduction plus difficiles et vice versa. Jusqu'à présent les convertisseurs catalytiques à MGP ont été capables de répondre à ces conditions. Sur le plan législatif, les Etats Unis prévoyaient pour 1976 une réduction d'environ 90 % des émissions des HC et de CO par rapport à l'état non réglementé d'avant 1969. Ces limites devaient atteindre 0,41 gr/mile pour les HC, 3,40 gr/mile pour le CO et 2 gr/mile pour les NO_x. L'application de ces limites a été soumise à une révision notamment en ce qui concerne une réduction ultérieure des limites pour les NO_x. Depuis 1975, le Japon a resserré sensiblement les normes à l'émission: 2,7 gr/Km pour CO, 0,39 gr/Km pour les HC et 1,6 gr/Km pour les NO_x. En 1976, il y a eu une réduction ultérieure de la limite pour les NO_x à 1,2 gr/Km et il est prévu en 1977 de porter cette limite à 0,4 gr/Km. Les normes sévères en matière d'émissions des NO_x vont obliger l'industrie automobile japonaise à étendre dans le futur l'utilisation des convertisseurs catalytiques à MGP. La Communauté européenne de son côté a réduit à partir du 1er octobre 1975, les émissions des NO_x de 20 %, de CO de 20 %, des HC de 15 % par rapport à la première réglementation de 1970. En outre, une limitation des émissions des NO_x, entrera en vigueur le 1er avril 1977. Des réductions ultérieures pour les trois polluants sont également envisagées.

2. ANALYSES DES SYSTEMES ANTIPOLLUTION

A côté du moteur Diesel qui produit peu de gaz polluants à cause d'une combustion plus complète, les principaux systèmes antipollution utilisés consistent en convertisseurs catalytiques et en moteurs spéciaux.

2.1. *Les convertisseurs catalytiques à MGP*

Ces convertisseurs catalytiques sont utilisés principalement pour réduire les émissions de gaz polluants dans le cas de voitures d'assez grosses cylindrées—cas des Etats Unis, notamment—mais leur emploi va très probablement s'étendre à cause de l'abaissement progressif des normes d'émissions.

L'utilisation des convertisseurs catalytiques à MGP présente plusieurs avantages du point de vue de l'amélioration de la qualité de l'air et de la consommation de combustibles:

— réduction considérable des émissions CO, HC et NO_x dans les gaz d'échappement répondant aux normes futures;
— utilisation d'essence pratiquement sans plomb (0,01 gr de Pb par litre);
— réduction variable mais sensible de la consommation de carburant (10 à 15 % suivant
— les types de convertisseurs) pour les voitures d'assez grosses cylindrées;
— récupération et recyclage possible du platine et du palladium.

Un inconvénient mineur de ces convertisseurs est la transformation du SO_2 en acide sulfurique (0·1 % de S en moyenne dans l'essence).

La fabrication du carburant spécial nécessite aussi l'emploi de platine en tant que catalyseur. Il existe actuellement deux types de convertisseurs catalytiques à Pt/Pd pour le processus d'oxydation, le type à "pellets" et le type monolithique. Tous deux utilisent un substratum en céramique comme support pour les métaux catalyseurs et l'ensemble est enfermé dans un container le plus souvent en acier, analogue au dispositif silencieux conventionnel.

L'un et l'autre type ont des avantages et des inconvénients mais maintiennent leur efficacité jusqu'environ 90 000 Km. Les quantités totales de platine—palladium (rapport 5/2) varient suivant la dimension depuis environ 1,5 gr (pellet type) jusqu'à 3 gr (type monolithe).

En ce qui concerne la réduction de NO_x, un type de convertisseur catalytique à base de ruthénium a été également mis au point.

Les deux systèmes catalytiques d'oxydation et de réduction peuvent être combinés ce qui élimine pratiquement toutes les émissions de polluants gazeux.

Les convertisseurs catalytiques à Pt/Pd ont été déjà adoptés par la plupart des constructeurs américains. Quelques constructeurs européens (et japonais) qui importent aux Etats Unis ont aussi pris une décision similaire.

2.2. *Les convertisseurs catalytiques à métaux de base*

De nombreux types de convertisseurs catalytiques à métaux de base ont été développés ces dernières années. Si le prix de la matière première est moins élevé que le platine, ils ont trois désavantages majeurs qui rendent finalement moins onéreux l'utilisation de convertisseurs à MGP.

— la dimension: les MGP ont plus efficients par unité de volume;
— le poids: ces convertisseurs ont un poids en moyenne 4 fois plus élevé que ceux à MGP;
— la durée: nettemment plus courte.

Il est donc peu probable que ces types de convertisseurs à métaux de base puissent remplacer les catalyseurs à MGP à moyen terme. Des efforts sont cependant en cours pour développer de nouveaux types de convertisseurs à métaux de base capables de répondre aux normes futures et de fonctionner avec de faibles quantités de plomb tétraéthyl.

2.3. *Les moteurs spéciaux*

Les moteurs spéciaux constituent une alternative possible aux convertisseurs catalytiques. Le développement se poursuit dans trois directions principales: les moteurs à charge stratifiée, Sterling et les turbines à gaz. Un type de moteur à charge stratifiée (stratified charge engine) a été mis au point initialement par Honda mais plusieurs firmes automobiles font un effort important de développement pour ce type de moteur qui permet une combustion plus complète et donc une réduction notable des émissions des trois gaz polluants principaux.

Les moteurs Sterling à combustion externe continue sont intéressants surtout pour les véhicules de grande puissance (camions, bus, etc). Il en est de même pour les turbines à gaz dont le principal handicap à surmonter est la consommation encore excessive de combustibles.

En conclusion, les Etats Unis ont opté pour les convertisseurs catalytiques à MGP, pour répondre aux normes en matière de pollution de l'air. L'adoption de ces catalyseurs par les principaux constructeurs américains (GM, Ford, Chrysler) n'a pas été sans difficulté.

Le Japon sera probablement obligé de suivre une ligne similaire tout au moins pour une certaine catégorie de véhicules à cause des normes sévères envisagées. Pour la CEE, il est

probable qu'en dehors des voitures exportées, les limites admises d'émission soient moins sévères ou acceptables pour le type moyen de cylindrée. Le développement de moteurs à charge stratifiée demandera une période de 3 à 5 ans et de ce fait ne pourra avoir un effet sur le taux de consommation des MGP qu'à partir de 1980. Une autre alternative est également l'extension de l'utilisation du moteur Diesel. Dans ce dernier cas cependant, les normes en matière d'émissions de NO_x pourraient amener également l'utilisation d'un système antipollution. D'une manière générale, il faut s'attendre à une certaine augmentation de la demande des MGP neufs dans le secteur automobile au moins jusqu'en 1980 puis à une diminution graduelle de cette demande surtout à partir de 1985.

Les MGP contribueront donc à une réduction considérable des émissions de gaz polluants dues à la circulation automobile. Il est possible que ces métaux trouvent de nouvelles applications dans la réduction des polluants gazeux émis par les centrales thermiques et le chauffage domestique.

3. AUTRES APPLICATIONS DES MGP DANS LA LUTTE ANTIPOLLUTION

Depuis 1972, le platine (anodes) intervient également pour la fabrication directe de l'hypochlorite de soude à partir de saumure (procédé chloropac). Ce procédé est utilisé pour le traitement des eaux urbaines et industrielles et commence à être appliqué aux Etats Unis en place du procédé au chlore. Des recherches sont également en cours pour appliquer le procédé chloropac au traitement des eaux potables.

Les MGP sont également utilisés pour l'élimination des substances contaminantes radioactives des eaux de refroidissement des centrales nucléaires.

4. ESTIMATION DES BESOINS FUTURS EN MGP

Suite à la demande de l'industrie automobile, les besoins en MGP en particulier le platine et le palladium vont augmenter d'une man ière appréciable. Plusieurs contrats de fourniture ont d'ailleurs été déjà signés avec les pays producteurs.

Les besoins en MGP dépendent d'une part du système de contrôle adopté et d'autre part d'un certain nombre de facteurs économiques et technologiques:

— la quantité de véhicules équipés de catalyseurs MGP,
— la quantité de métal précieux utilisée dans les convertisseurs,
— la quantité de métal susceptible d'être recyclé,
— la substitution par d'autres systèmes et son échéance probable.

L'ensemble de ce problème a fait l'objet d'une étude détaillée et régionale pour le compte de la Commission des Communautés européennes. Il ne nous est pas possible ici d'entrer dans les détails.

TABLEAU 2

(en tonnes métriques)

Secteurs	1974	1977	1980	1983	1985
Automobiles	10	30	40	40	40
Industrie	115	135	145	165	185
Joaillerie	35	38	40	45	47
Total	160	203	225	250	272

En résumé, les prévisions des besoins probables en MGP (métal neuf) pour le monde occidental sont indiquées au Tableau 2.

Les réserves exploitables de MGP actuellement connues dans le monde estimées à quelque 37 000 tonnes métriques sont donc en principe susceptibles de satisfaire l'accroissement des besoins à long terme, compte tenu de la consommation des pays communistes.

5. CONCLUSION

Les métaux du groupe du platine en particulier le platine et le palladium offrent donc de bonnes perspectives dans la lutte antipollution et sont susceptibles de contribuer de façon appréciable à l'amélioration de la qualité de notre environnement et notamment de l'air.

SULPHIDIC OXIDE EMISSIONS

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The emission of sulphur dioxide is regarded by some people as atmospheric pollution and by others as a method of recycling a waste product of combustion to vegetation which needs it. Yesterday we had discussion on returning waste products to the land. Nitrogen, phosphorus, and potash were mentioned, but not sulphur, which is equally important.

1. This first slide shows that sulphur is washed out of soil and accumulates in the sea. Sulphur has to be continually supplied to the land year by year, as otherwise it will soon be insufficient for maximum crop growth.

2. These plants were grown in filtered air in the greenhouse of the Grasslands Research Institute on soil taken from outside. On the left, sulphate has been added to the soil and they are growing well. On the right they are stunted because of insufficient sulphur. But outside they grow well on this same soil because they can get their sulphur from the air.

3. The old traditional fertilizers had plenty of sulphur in them.

4. Modern fertilizers have very little sulphur.

5. This shows how plants use various gases from the air. The utilization of sulphur dioxide has similarities with carbon dioxide except that plants have to be much more efficient in capturing sulphur dioxide if they are to get enough.

6. They get enough because in addition to absorption through the leaf pores sulphur reaches them also in other ways.

7. You may wonder why therefore sulphur dioxide has got such a bad name. This photograph of the City of Liverpool shows smoke from the chimneys going down into the streets. Of course, that is old-type housing.

8. But these nice new modern bungalows are just as bad.

9. Here is the chimney of a new school. The architect made an architectural feature instead of a good chimney. It is too wide, so the gases go up it very slowly. He has put a lid on top to keep the rain out. The gases do not mix and disperse properly in the air. You can see that the near side of the tree across the road is damaged, but not the far side. Here we have an example on the scale of a few metres of the kind of damage which has occurred downwind of large smelter plants at Trail and Sudbury in Canada on the scale of kilometres.

10. This diagram shows the effect of different kinds of chimneys. Sufficiently large chimneys will cause dilution of the gases, will take them above an inversion layer, and will

not contaminate the air at breathing level until the dilution has reduced the concentration to a harmless value.

11. While that was a diagram which anybody can draw, here is a photograph taken over an inversion cloud layer over London. You see the gases not only from power stations but from factories, such as a sugar refinery, coming up through the layer instead of polluting the air that people breathe below.

12. Here is the actual record over 20 years: a 50% fall in the sulphur dioxide that people breathe, while there has been an increase of 20% in total emissions. On the same scale I have shown the emissions for the U.S.A. You can see that they are too small to worry about.

13. This summary of the effects of various concentrations of sulphur dioxide shows that the ideal for recycling sulphur back into vegetation is around 30–40 $\mu g/m^3$. Above 70 $\mu g/m^3$ we begin to have trouble, and below 10 $\mu g/m^3$ there is sulphur deficiency.

DISCUSSION

HIGBIE: I would like to ask Don Klumb from Union Electric Company a question which ties the subject of sulfur dioxide found in powerplant stack gas emissions to the subject of resource recovery. We know that paper is one of the lowest sulfur-containing fuels now available and its use as a fuel supplement when burning high-sulfur coals should reduce the generation of sulfur oxides which are eventually emitted to the atmosphere. Would you please tell us how effective the burning of paper has been to reduce sulfur oxide gaseous emissions in the current operation at the Union Electric Company?

KLUMB: We are not using a higher percentage because it is not available. We are incapable of collecting enough material. We have a capacity to burn something like 30,000 to 40,000 tons of solid waste a day. We just can't get enough of it. We're reaching out now 150 miles, looking for material. It's not that we don't like it—it's just that we don't have enough of it.

SIKKA: I'd like to ask Professor Rubin how far the materials move? Because that is one question that most people have not touched. We have been talking about pollution of water, subsurface water, but what we want to know is how far some of the pollutants can be traced and how far are their effects?

RUBIN: There is no general answer to this question. The answer depends on the material which is moving and on circumstances under which it is moving, that is, on the system characteristics. Let's take two extreme examples. First, consider that the moving substance of interest is chloride. One may be interested in chloride because, say, due to excessive pumping, salt water is moving into an aquifer. Well, chloride does not react with the matrix, i.e. sediments, so it moves relatively fast. In addition, obviously, its movement depends on how fast the ground water is flowing and on the dispersive properties of the aquifer. On the other hand, consider something which exchanges or reacts—say one puts dissolved cadmium into a carbonaceous environment. Well, cadmium will precipitate, and hence will be moving very slowly, if at all. It follows from these examples that there is no general answer. If one wants an answer for a particular problem *before* the pollutant is introduced, one has to model the situation on hand: one must construct a model; measure the relevant parameters; introduce these parameters into the model, and then, for one's particular circumstances, an appropriate answer will be obtained. If, in the course of time, we shall gather enough experience under various circumstances, perhaps we shall be able to give some very general "global average" answers which are encountered at this conference. Today, we really have difficulty in giving such answers. But what can be pointed out here is that if one does not take into account the actual local circumstances, one might choose controlling rates, which would be meaningless. They might be one, two, or three orders of magnitude wrong for a given location. And it is pollution at a given location, not the global average pollution, which most often counts.

LOCKE: Gentlemen, may I raise two issues which are in my mind, which haven't been touched on but do seem relevant to what's been said. The first is the matter of the economics of acceptability to society; in our case, the economics of environmentally acceptable processes. Today and yesterday it does seem to have been assumed that one has positively to pay for having a decent environment as compared with the sort of environment one would have as a result of using current processes. But I'd like to question this. In our work in the National Research Development Corporation in Britain, whose job is to take new science and turn it into industrially useful processes, we have many dozens of process variants, and improvements, including recycling techniques, reclamation processes, and alternative new processes, that show actual economic advantage over the processes which are being applied and used today. In other words, one does not necessarily have to pay for a decent environment.

This is important because we're concerned in NRDC with the development of processes that do show some economic advantage. I won't go into the details of the sorts of processes that we're concerned with because that would take too long and we're at too late a stage in today's meeting. But to give you a few examples: we are developing and have licensed and in operation a new approach to steel making, which reduces the needs for expensive fume-precipitation equipment and enables old open-hearth furnaces to go on being used profitably for much longer, simply because the iron oxide fume hitherto emitted as a great pall of red smoke over open-hearth furances is no longer formed. The steel thus produced is actually cheaper and can also have purely technical advantages. In recycling, we're concerned, for example, with highly-profitable processes for recovery of plasticizers from scrap plastic that would otherwise be dumped. This makes money. In Britain, we're reclaiming many materials where the cost of reclamation is more than made up by the sales of products resulting from the reclamation. Nickel, copper, and other metals such as tin have obvious value, but in some cases reclamation of waste plastics can be worthwhile for reuse as plastics directly if the application is suitable. As we go forward in our work we find that there are all sorts of opportunities for new industry, from an environmental point of view. New filters, new biological oxidation plants, new instrumentation, ancillary equipment such as pneumatic conveyors, etc., can all play an environmentally useful part, as well as a technological development part, in the advance of industry as a whole.

Then, there is the question of substitution of new processes. We are, for example, involved in fluidized combustion, which is a means of burning fuels, however sulphurous, with negligible environmental prob-

lems from sulphur dioxide. This is not to say that Mr. Ross is not perfectly right when he says that some sulphur dioxide is desirable in the atmosphere—the important point is to be able to control it economically. The fluidized combustion work I mention because there are so many Americans here and several Swedes and so on. We're working closely with the American Government and also with organizations in Sweden, France, and elsewhere as well. The technology makes it possible to use dirty fuels, in advanced combined cycles, to generate power at high efficiency in an environmentally clean manner, and more cheaply than by conventional means. Another example of a new process we are working on is called "formed coke", which makes a reductant for the steel industry and which not only extends, as does fluidized combustion, the range of raw fuels one could use in the process; it also means that the process can be performed environmentally much more cleanly than can conventional coke-making processes.

Secondly, and in quite a different line, I'd like to suggest the addition of another proposal to those which arose out of the discussion this morning. As well as the six proposals that have already been made as recommendations from here, dealing with a reduction of increase of demands on resources and raising living standards, improving education and knowledge, working towards balance of development of resources and uses and so on, there is another—that mankind as a whole needs to consider more carefully what is required from science, or what man requires from science. Perhaps we ought in future to aim for a little more spreading-around of the possible benefits of science, to all people, rather than just making great advances in particular directions to benefit some. I'm not saying anything against far-reaching advances in specific directions: obviously, if it could be achieved, a cancer cure or a cancer control, for example, would be a very good thing.

But I'm concerned at this stage with the whole of science and the purposes for which the science is used. When science is publicly funded—paid for as university research by government agencies and research bodies, for example, it is very largely for the purpose of increasing the intellectual resource, so to speak, of the world, and this, I'm firmly convinced, is a very good thing. But when we come to use the results of science, we tend—if we're not very careful—to take a rather too short-term view. We tend to consider what can be profitable (or even economic) in the fairly short-term future. Our work in NRDC shows that if one takes a slightly longer-term view, one can still make profit on the right schemes. But here I'm suggesting that one needs to take—so far as concerns a conference like this—an even longer-term view. This Institute is concerned essentially with quality of life, and that involves so many other aspects than just medium-term or short-term economics, that we should add a seventh recommendation: to do with the spreading around of understanding of the sort of science that we have and of the benefits that can be achieved. I say this particularly because these days there does seem to be a growing risk of a gap between people and technology. It is almost a gap between people and progress. All the technologists in this room and elsewhere in this building, and civil servants and industrialists and planners and developers and forecasters, and so on—all sincerely believe that their efforts contribute to progress for the public good. And yet, you know, people frequently find themselves, when they consider things from a personal point of view, that progress tends to leave them behind.

People are glad of and accept warm houses and solid footpaths, and well-lit streets and easy transport and uncontaminated food and cheap clothes, and the many other benefits of industrialized life. But, at the same time, quite understandably, they're not entirely happy . . . they grumble about polluted air and beautiful buildings pulled down to make way for new ones, and old buildings that fall down because of the vibration on the road caused by heavy lorries. They grumble at the littered countryside and at noisy flight paths under their aeroplanes, worry about unwelcome aspects of systems technology, resent sewage in the sea, and fear safety aspects of novel science and technology. There are many other examples. All of these things could quite simply be dealt with by technology, thought, and organization. But as a world we lack adequate means of communication out from, and back to, the scientists and the technologists, the industrialists and the progress makers. We lack real understanding at the interface between these categories of people and the ordinary people that are outside this room—for that matter, the ordinary people we ourselves become as individuals when we leave a room like this. I would like to hope that this Institute of Quality of Life could make as one of its recommendations the setting up of deliberate operating interfaces between those who organize progress and those who undergo its effects. This would require organization, perhaps via UNESCO. It will be important to ensure good flow through such interfaces in both directions, both of information and of encouragement to discuss and reconcile issues.

JOY: I think we had better turn to Professor Harrison Brown to give his comments on the summing-up.

BROWN: Thank you very much, Professor Joy. I am very sorry for the fact that we pushed you so hard, but I gather that the discussions were nevertheless useful. In about 15 minutes, this meeting will be adjourned and a drafting group is going to start working. It will be very useful to have some suggestions from this group as to what—if anything—we would like to recommend. There are various degrees. I believe that there would be a chance that we would get unanimous agreement on any one fact or any one principle, but we can talk in terms of the consensus, we can talk in terms of a general agreement or a feeling that there was an agreement and so forth, which we will probably have to do. Mr. McKelvey presented for our consideration a series of possible resolutions. These need not be presented in the final document as

resolutions; they could be presented as suggestions, conclusions and so forth. So I open the floor now for discussion, reactions to individual items that have been suggested and proposals for others.

RUBIN: I would suggest that we divide our recommendations into two parts: (1) technical recommendations; (2) general recommendations. In connection with the technical recommendations, note that we are a technical group, we talked almost exclusively about definite technical problems, like depletion of mineral resources, the recycling problem, the waste-disposal problem. Hence, our technical opinions are particularly relevant to the conference. In connection with every topic we considered we should attempt to define the problem, and state what action do we think is needed in order to solve it. The action in question should include research and development as well as societal action. I think that we should develop these technical recommendations first. Then we can consider the second type of recommendations. These are like many of the recommendations presented by Dr. McKelvey. They are general recommendations which we make when we consider ourselves as a part of the conference as a whole and as concerned citizens of the world.

DYKE: There are two points I would like to make, Mr. Chairman. One following on Mr. Locke. I'm wondering if it is possible to set up a trust within the Institute that would harbour technical ideas, to get these spread across the board, which I think is what we've got to have, and to distribute the values that devolve from this accumulation of ideas so that we don't get multiple parallel practice in the development area. There would need to be some means whereby a reward is placed where it belongs, where you get the original innovation and work. I don't know if it's practical, but it does seem to me an area for exploration in that field. The other point, I think we have over concentrated on the recycling of the waste product. This is my area and I am commercially concerned here. This is my bread and butter. But I do admit that the more I look into this problem, the more we have got to think of the savings all along the line, from primary extraction right down to the end product. The end product waste is a fraction of your total resource use, in the production and utility areas. If you take the high cost of recovery and set this against a 5% saving in resource use (which we can get) we had a 3-day working week in the U.K., for example, and a 4.2-day working utility. This is worth looking at. We are up against Parkinson's Law, I'm quite sure. If you dig a big enough hole you can fill it. It's always the gap that gets filled up. I think if we were to effect savings in consumption this is where we would score.

SIKKA: I agree with Professor Rubin that we should divide between the technical and nontechnical opinions of various branches. We have spent considerable time in discussing recycling of wastes, recovery of materials of waste. Many people would get the impression that it may be easier to recycle and recover materials out of waste than to look and search for minerals or developed resources. I'd like to cite one or two examples which I have seen in the past. A few years ago there was a thought that we should substitute aluminum for copper and at home we did start looking for substitution rather than finding more copper and developing. This year we are talking about a substitute for steel, because we don't produce enough steel. This type of talk which we have been doing for the last 1½ days could give the same impression to many people. What I want to point out is that recycling of waste materials under renewal resources and environment are essential in highly developed countries, and technologies may be required to a lesser degree at present in the less-developed countries. Therefore a distinction needs to be drawn in order that people in the less-developed countries do not become complexed about the development of their resources. Two, the problem of basic recycling has arisen because of the cheap availability of raw materials in the past. Had higher prices been paid earlier, some of the problems may not have arisen. And may have been solved. Maybe we should consider paying higher prices for the raw materials to offset the cost of environmental protection which the underdeveloped or less-developed countries will have to invest in their countries in future to avoid pollution which highly developed countries are now facing. Three, the real problem is not overpopulation or population growth, but the highly developed countries conserve more resources and they consume more and more. If this consumption can be controlled by techno-economic developments, maybe we can solve some of the problems confronting mankind. Four, one question this conference needs to answer is: Are we running short of resources—mineral resources I mean—if so, what would be the effect on mankind? Still we have not proved that scarcity is about to come or has come. The conference, and especially this group, should consider this question and should give an answer. This is one of the prime purposes of our being here, for the effort needed in terms of manpower, education, and training need to be mentioned.

BROWN: Thank you very much. I hope you can submit those to the conference.

GOMES DA COSTA: I would like to support the opinion just expressed here by the distinguished delegate from India. We in Brazil are a country with 18½ million km² We know very little, geologically, of our country. So to us, it is very strange, this talk of the scarcity of minerals. Like Brazil, I think there are a lot of other countries that would find this kind of talk strange too. We, in the last years, have had a very high rate of our growth national product and we intend to proceed in the same way with or without waste. It is essential for us to develop our resources, but we don't want to do it alone. Because Brazil is open-minded to foreign investment, but we want to enjoy foreign investments to have a just price for our natural resources. I got the impression in the last days that with the effects and not with the goals of waste products. As a matter of fact I got the impression that if the trend goes on, as seems to have been

indicated here, we would have a waste-disposal industry so strong as to be a branch of the economy that each day we should have more waste to have the economy in good shape! That's not a joke. That's really the impression I had. On the other hand, I think that science and technology and the education could try to find a way of lessening the generation of waste and not treat always the disposal of waste.

PARIZEK: We have a mechanical problem just on time because according to my watch there are about four minutes and I'm concerned about what we're going to hear in the next several days that may fall out of our group. I was wondering whether or not the suggestions of breaking it down into working sessions and perhaps putting some of us to work this evening would perhaps be a good use of the time remaining. I've come a long way as a guest and I'm prepared to work. I'm sure there are other people here who would be willing to work this evening. Rather than having two or three people having to go off and write what they believed to be the findings of this group, could we not assign or break it down into little assginments and work this evening? To help you out because you must have a serious task ahead of you.

BROWN: It is quite clear that whatever is written and reported, the conference as a whole is not going to be very long, nor will it be very detailed. My understanding is that there will be plenty of time for discussion during the course of the next 3 days concerning all of the facets of the problems that are being taken up by the conference. My own feeling is that we probably will not wish to be quite as specific in our suggestions as these particular items listed by Mr. McKelvey appear to be. This is something that we will have to discuss. I am somewhat mystified that the organizers of the conference did not provide more instructions as to exactly what they expected our group to do. I suspect that there will be an opportunity for assignments to be made. I would be reluctant to do it now until we consult the heads, the chairmen of other groups and with the overall organizers of the conference, to find out in more detail just what is expected of us. I would hate to break ourselves up into 25 working groups tonight and have everyone stay up until 3 o'clock in the morning and then find out that this has not been useful. So we're just trying to get a feeling now for reactions.

CLOUD: Well, Harrison, it is awfully late and I don't think we're going to resolve anything here this afternoon. But I'd like to say just a few words in response to some of the discussions I have heard. As a member of an affluent country and a relatively affluent member of an affluent country, I would be very happy to give up some of my affluence if I thought it would help anybody else. Indeed my own life is a relatively simple one. It is by design not highly material consuming. I think probably one thing we might all agree on as a goal here is that we do wish—really and truly—to improve the lot of deprived peoples everywhere, whether they be in ghettos in some great city in an affluent country or in some small traditionally poor tribal region. But if we think in terms of doing this, with present world resources, and then if we project this at present rates of increase of world population among the poor and consumption among the rich, when is it going to happen? You yourself back in 1954 made some interesting projections about how much new raw materials would have to be put into circulation to raise the level of living generally to that then prevailing in affluent countries. Let us take one of the less affluent countries of Western Europe. If we want to raise the level of everyone, everywhere in the world to that level, how do we do it? We would have to have literally—even at present population—a production equivalent to hundreds of years of production in current terms, to achieve this even by the year 2000. Yet even if world populations were today to go to a bare replacement level of growth, population, because of age patterns, would still continue to increase for another 70 years and world populations would increase by 50%. At the faster rates of growth prevailing we wipe our gains in food and materials production faster than we're able to make them. The fundamental proposition is contained in McKelvey's six statements. These are humane propositions, aimed toward a more equitable distribution of the wealth and the goal of improving the lot of the underprivileged. If we as a group endorse nothing else I wish we'd endorse that.

AUBERT: Je voudrais simplement indiquer combien je suis d'accord avec ce qui a été dit par notre collègue le Dr. Rubin à propos de recommandations et résolutions que nous devrons prendre et combien je suis d'accord avec notre collègue des Indes.

HEALING: In the remarks, I would very much like to support the six points proposed by Dr. McKelvey as being the basis of the report of this working party to the plenary session. Whether or not some additional technical points or recommendations are made, I think is of secondary importance. I admit that a great deal of the discussion in the last day and a half, particularly today, has been very much concerned with technology. However, I think the amount of time given to the discussion, important as it is, does not necessarily reflect the true importance of the working group's discussion. I therefore feel that Dr. McKelvey's six points, in particular his first point, in which he proposes a recommendation to the effect that developed countries should aim towards reducing their rates of increase in consumption of mineral resources and mineral fuels, is probably the most important single recommendation that this working group can make. My only regret is that it cannot be put more specifically, that is, as to how such reduction in the rate of increase can be brought about. I'm afraid that in the last day and a half there has been comparatively little discussion of this question as a whole and I strongly feel that the way this could be brought about is for the consumers of mineral resources to be faced with the total resource cost of those resources they are consuming. This would partly come from providing the primary producing countries with higher prices for

their mineral products, but it might also necessitate in my opinion the intervention of governments in the consuming countries by fiscal means, to ensure that the consumers in those countries paid the true resource cost and therefore were more economic and efficient in their use of products and hence would generate less waste.

BERCÈ: I would rather make a suggestion to the working group. In the time we have spent together, the discussion has been leveled from one country to another one, which indicates that the problems involved are various and very different. Therefore the basic measure is completely different when passing from one to another country. Consequently our conclusions should be leveled and measured with the same measure-unity and not influenced by the measures actually employed whether on one side or another.

RUIZ: I would like to make some comments on the Point Two of Mr. McKelvey's proposals of resolutions, saying that the governments and intergovernmental bodies should endeavor to improve the level of living of the underdeveloped countries mainly if not only, through a better internal distribution of income, considering the need of the conservation of the non-renewable resources. I consider this proposal unjust for the underdeveloped countries, for it means that if a country has an average per capita income of, say $200 or $500 the only way they can afford to improve their level of living is to distribute in an equitable way that small amount of income. If the future world supply of resources is considered so hopeless, I think it is necessary to share the sacrifices between the developed and the underdeveloped countries allowing the increase of standard of life of the latter.

BROWN: Yes, you're right. I completely agree with that. There needs to be some rewording there. You'll be at the very last, Mr. Vice-Chairman.

GUILLEMIN: Au sujet de la possibilité d'un développement encore considérable de la consommation en métaux, on sait que dans les pays développés on tendait déjà vers un palier. Ce palier était déjà visible pour certains métaux très utilisés comme le cuivre, le zinc, le plomb. Il est possible que la déflation—car il faut tout de même considérer que nous sommes dans un monde où l'économie joue un grand rôle et pour l'instant il se passe des choses du point de vue économique depuis deux au trois jours—la déflation qui pourrait parfaitement arriver devrait tendre à accélérer le passage sur palier et donc à ce que la croissance en consommation de métaux par tête dans les pays développés diminue ou du moins se stabilise. Pour les pays en voie de développement qui actuellement consomment extrêmement peu puisque 2 milliards d'individus consomment 10% de la consommation totale en métaux il y a deux cas:

— ou bien ils sont riches, c'est-à-dire qu'ils disposent de réserves importantes en produits énergétiques. Ce sont les pays arabes et les pays golfe de Guinée. Ces pays riches représentent 200 millions d'individus donc même si leur consommation par tête en métaux devient équivalente à celle des américains, cela ne représentera pas une augmentation considérable de la production de métaux.
— pour les autres, pour les 2 milliards d'individus restants, qui eux sont chaque jour plus pauvres avec la crise de l'énergie et avec les prix augmentant pour le pétrole et les autres matières premières, il est certain qu'avant de se servir de métaux, ils auront tendance à manger, tout au moins ils essaieront, et donc je ne pense pas que là aussi la consommation en métaux puisse augmenter considérablement dans les 10 ou 20 prochaines années.

C'est pour cela que je pense que toutes les courbes qui sont faites actuellement et tous les raisonnements qui sont basés sur mettons un doublement de la consommation en métaux d'ici l'an 2000, sont profondément faux. Si nous arrivons simplement à multiplier par 1,5 la consommation ce sera déjà relativement considérable même en tenant compte de l'augmentation démographique—l'augmentation démographique jouant très peu dans les pays riches et jouant essentiellement dans les pays pauvres qui auront de moins en moins de moyens pour se procurer des métaux.

Si nous reprenons les chiffres qui ont été donnés par le Dr. Cloud pour le cuivre en particulier, il donne comme possibilité de production totale du cuivre un chiffre compris entre 1 milliard et 10 milliards de tonnes métriques. Il estime que cela nous conduirait à peu près à épuiser les gisements de cuivre vers 2050. En 2050, mettons que nous soyons environ 10 milliards d'individus sur la planète, cela donnerait donc par tête d'individu une quantité de cuivre comprise entre 200 et 600 kg. Ce qui représente tout de même quelque chose d'assez considérable étant donné qu'actuellement on estime que la quantité de cuivre par habitant de la planète est inférieure à 30 kg. Là aussi, on a vraiment l'impression que les gens peuvent augmenter considérablement leur stock métal alors qu'en réalité on sait parfaitement que l'espace est limité, que dans un appartement on ne peut pas mettre 300 kg de cuivre, c'est totalement impossible; il y a une limite qui est une limite physique de consommation des métaux par tête d'habitant.

JOY: It was a little unfortunate, I think that God was not here at the beginning of this afternoon's session, where we were making the particular emphasis on the need to plan and to think. I think for a useful suggestion in this short term, that we may see something happening in 5 years, in that rather more efforts are made along the lines represented in these first three papers, of attempts to get even some crude, overall models of the interactions of the economic pressures and legal pressures which could realistically be applied and if possible take the type of work of Dr. Rubin in attempting to get finer models pushed, because there is altogether far too much what we would c

thinking. That is what I feel should be one of the resolutions for some rather more positive thinking and if it can be made semi-mathematical, the better.

BROWN: Thank you very much. The meeting is adjourned.

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PREFACE

L' INSTITUT DE LA VIE a pour objet:

— d'engager d'une manière permanente une réflexion fondamentale et appliquée, théorique et pratique, sur la vie et la condition humaine, qu'il s'agisse de notre espèce dans la biosphère ou de l'homme dans toutes ses dimensions;

— de rassembler les plus hautes compétences scientifiques et techniques pour rechercher à chaque instant dans le pluralisme des disciplines et des philosophies les solutions les mieux adaptées aux besoins et aux aspirations des humains et d'aider ainsi la décision de ceux qui se trouvent investis des plus hautes responsabilités;

— d'établir un courant d'échanges entre les hommes à tous niveaux pour les sensibiliser à la valeur de la vie et les éduquer à la respecter.

L'INSTITUT DE LA VIE a organisé, du 9 au 14 septembre 1974, une conférence mondiale sur le thème:

"VERS UN PLAN D'ACTIONS POUR L'HUMANITE:
BESOINS ET RESSOURCES—METHODES DE PREVISION"

à laquelle ont participé 236 personnalités appartenant à 29 pays.

Cinq thèmes ont été choisis qui ont fait chacun l'objet, en septembre et octobre 1973, d'un colloque préparatoire. Les travaux de ces colloques ont été publiés dans l'ouvrage "VERS UN PLAN D'ACTIONS POUR L'HUMANITE—PROBLEMES ET PERSPECTIVES".[1]

Les actes de la conférence elle-même sont publiés en cinq volumes.

Cette manifestation sera suivie de nombreuses autres inspirées par la même volonté de poursuivre l'aventure humaine et de permettre à l'homme de vivre et de s'accomplir.

L'INSTITUT DE LA VIE soutiendra tous les quatre ans le même effort concerté de réflexion universelle.

L'INSTITUT DE LA VIE est le point de rencontre des inquiétudes, des espoirs et des volontés. Il est le lieu de la prise de conscience, de la mise en alerte. Il veille aux postes avancées de gardien de la vie. Il pose les équations de l'avenir et du salut. Prise de conscience, prise de confiance puisque tout désespoir est désormais porteur de néant. Confiance dans notre capacité de trouver des solutions neuves à des situations neuves, confiance dans l'homme, confiance dans l'esprit, confiance dans la vie.

M. MAROIS

[1] North-Holland Publishing Company, 335 Jan Van Galenstraat, P.O. Box 103, Amsterdam-W, The Netherlands, M. MAROIS, editor, 1974, 558 pages.

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TOWARDS A PLAN OF ACTIONS FOR MANKIND

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SOURCES ET TECHNIQUES NOUVELLES EN MATIERE D'ENERGIE APRES L'AN 2000

R. Gibrat

Le choix de l'an 2000 est bon pour permettre une réflexion sereine et ne vaut pas seulement par l'attrait d'un nombre rond traditionnellement chargé de mystère.

a) D'ici l'an 2000 aucune source nouvelle d'énergie ne pourra intervenir de façon significative.
b) Les deux grandes aventures techniques en cours de développement aujourd'hui dans le domaine de l'énergie, sont indiscutablement les surrégénérateurs et les réacteurs à haute température dits HTR. Mais leurs succès ou leurs échecs n'auront pas une influence décisive sur le déroulement de la période qui nous sépare de l'an 2000.
c) L'évolution des mœurs ou les mesures autoritaires qui seront peut être prises par certains états en matière de contrôle des naissances ne peuvent mathématiquement pas modifier sérieusement le niveau de la population en l'an 2000.
d) Dans le monde occidental, tout au moins, les ressources naturelles (charbon, gaz naturel, fuel oil . . .), avec notre taux de croissance actuel se rapprochent lentement de leur fin. De plus, les problèmes d'environnement rendent chaque jour leur utilisation de plus en plus difficile. Les hautes teneurs en soufre, surtout en combinaison avec l'ozone et les oxydes d'azote, apparaissent désormais insupportables. La pollution par les automobiles ou les avions fait l'objet de violentes attaques et il ne faut pas compter sur un retour en arrière important de l'opinion publique. Chacun ou presque s'accorde à sonner pour l'an 2000 le glas des combustibles fossiles. Leur disparition totale parait peu probable, une diminution considérable de leur rôle par contre est très souhaitable.
e) Nous connaissons, surtout depuis 1968, sur ces problèmes un bouillonnement extraordinaire d'idées: contestation de notre civilisation technique, discussion sur le taux de croissance industrielle, prise de conscience très vive des problèmes d'environnement et de qualité de la vie, industrialisation des pays en cours de développement. Les conséquences de tout cela sur l'an 2000 commencent, grâce à la crise actuelle, à apparaitre plus clairement.

Nous avons pris, à titre d'hypothèse moyenne, les données suivantes pour caractériser l'approche de l'an 2000:

a) Un taux de croissance économique modéré, mais correspondant à un développement industriel important du tiers monde, d'où une consommation mondiale d'énergie en 2000, trois à cinq fois plus forte que le niveau actuel.

b) Un grand respect de l'environnement par une recherche continuelle des conditions de son amélioration. On a parlé de croissance zéro de la pollution, c'est désirable, ce n'est peut être pas possible.
c) Une attention de plus en plus grande apportée à une bonne solution des problèmes d'autarcie, c'est à dire une certaine indépendance dans les ressources énergétiques d'un pays déterminé.

Nos hypothèses sont très larges et écartent toutes discussions de chiffres. Au paramètre ressources à prix convenable, seul facteur autrefois en jeu, nous en ajouterons deux nouveaux aussi importants: environnement et autarcie.

En conséquence de ces trois hypothèses, l'électricité pourra en l'an 2000 assurer 40 à 50% des besoins d'énergie totale, le nucléaire prenant la plus grande part possible de la production d'électricité, 80% par exemple. De plus le phénomène extraordinaire de la surrégénération commencera, à partir de 2000, à peser de plus en plus; aussi dans les premières décennies du XXI^e siècle, la production nucléaire jouira d'une autarcie à peu près totale, le combustible nucléaire devenant un sous-produit de la production d'électricité.

S'il en est bien ainsi, les problèmes de ressources et d'autarcie seront reportés sur la partie de la consommation d'énergie couverte aujourd'hui par les hydrocarbures. L'électricité pourra peut-être en prendre une part progressivement, mais un envahissement brutal et total est évidemment impossible.

Si on écarte le retour au charbon, comme cela semble probable sauf peut-être aux USA et en Pologne, la principale solution en vue est dans l'utilisation de la filière nucléaire des réacteurs à haute température dite HTR permettant une production en masse d'hydrogène à partir de l'eau; car de nombreux débouchés inaccessibles ou très difficilement accessibles aujourd'hui à l'électricité pourraient alors ressortir directement du nucléaire à travers l'hydrogène.

Toute une structure énergétique nouvelle pourrait ainsi se créer grâce aux propriétés exceptionnelles de l'hydrogène en matière de transport, de stockage et à son absence de pollution à l'utilisation, au moins en principe.

Ainsi, surrégénération et hydrogène seraient, grâce aux réacteurs nucléaires, les deux notions clefs capables de transformer les premières décennies du XXI^e siècle. En cas de réussite, les problèmes de ressources et d'autarcie seraient pratiquement résolus. Cette solution "tout nucléaire" parait ainsi la mieux adaptée aux problèmes du prochain siècle. Mais en étudiant ses propriétés vis à vis de l'environnement, nous trouverons les limites de son extension, la nature profonde de l'homme ne pouvant, à notre avis, supporter les tentations trop fortes qu'elle lui apportera.

Pour cette raison, mais aussi parce que que des échecs ou des retards sont possibles (un grave accident nucléaire entraînerait sans doute un effet de rejet temporaire du nucléaire par l'opinion publique), le recours à des sources nouvelles apparait nécessaire.

Nous passerons donc en revue dans un chapitre intitulé "Solutions lointaines" les divers flux naturels d'énergie qui nous entourent et que nous pouvons songer à capter. Trois seulement nous apparaitront capables de jouer un rôle massif à l'échelle mondiale: énergie solaire, énergie géothermique, fusion nucléaire. On a écrit souvent que les quantités d'énergie correspondantes sont illimitées et que leurs propriétés autarciques sont excellentes. Ceci mérite en tout cas d'être examiné.

Mais auparavant, dans le deuxième chapitre, nous aurons retenu certaines autres sources déjà prêtes ou presque, mais dont l'influence sera surtout locale. Nous pensons par exemple

aux marémotrices pour la France. Nous aurons aussi à examiner certaines techniques avancées de conversion, stockage, transport qui peuvent intervenir dans tous les cas pour faciliter l'exploitation.

Toutes les solutions, quelles qu'elles soient, posent des problèmes climatologiques et cela fixera des limites à leur utilisation, donc à la production d'énergie, donc à la croissance industrielle. Ceci fera l'objet de notre dernier chapitre.

PREMIER CHAPITRE: TOUT NUCLEAIRE

"Tout nucléaire" ne doit pas être confondu avec le slogan actuel d'EdF "tout nucléaire, tout électrique" car le "tout nucléaire" suppose ici l'introduction d'un nouveau vecteur d'énergie à côté de l'électricité: l'hydrogène. Trois domaines doivent donc être évoqués: la surrégénération, les réacteurs à haute température, l'hydrogène.

La probabilité de résoudre avant l'an 2000 les problèmes posés est grande, car pour les trois domaines:

a) il y a déjà aujourd'hui des structures industrielles puissantes d'études, de développement, puis d'accueil;
b) les problèmes paraissent tous recensés, sinon résolus;
c) on peut fixer raisonnablement des délais d'introduction industrielle;
d) on connait bien leurs atteintes à l'environnement.

Pour les "solutions lointaines", c'est très exactement le contraire sur ces quatre points.

I. Surrégénération

C'est un phénomène extraordinaire qui, à lui seul, apportera une mutation révolutionnaire des problèmes énergétiques. Grâce à lui on peut envisager de transformer presque tout l'uranium fertile en énergie et ainsi multiplier le rendement actuel par cent ou presque. Les réserves mondiales actuellement connues représenteront par ce seul fait cent fois plus d'énergie que maintenant, ceci est déjà extraordinaire; mais de plus on pourra exploiter des minerais à teneur beaucoup plus faible, d'où des ressources pratiquement illimitées supprimant pour longtemps toute controverse sur les réserves en uranium.

Aujourd'hui, ce type de réacteur est proche de la réalisation industrielle, le prototype français a très bien débuté. Il est donc très probable que la matière fissile, source première de l'énergie nucléaire, deviendra pour un certain taux de croissance de la production un sous-produit de l'activité industrielle, la régénération des matières fissiles par la surrégénération annulant pratiquement tout approvisionnement extérieur en matières premières. On ne saurait imaginer solution plus étonnante et plus parfaite des problèmes de ressources et d'autarcie.

II. Réacteurs à haute température (HTR)

C'est la seule filière nucléaire qui permette la production de chaleur à haute température comme fluide de refroidissement d'un gaz chimiquement inerte, l'hélium. Elle existe sous deux versions: aux USA avec l'activité atomique de deux sociétés pétrolières amies (Gulf et Royal Dutch); en Allemagne avec un groupe d'industriels soutenus par l'Etat. En France,

divers accords lient avec la Gulf, l'Industrie, le CEA et le Gaz de France. Les Allemands ont atteint en février 1974 une température de l'hélium à la sortie de 950°.

Un réacteur industriel le THTR (Thorium High Température Réacteur), de 300 MWe est en cours de construction. Le gaz sortira à 750° environ, mais une procédé à l'étude, le procédé OTTO, avec un seul parcours de combustible dans le cœur, fait espérer 100 à 200°C de plus. Enfin, en 1973, un agrément a été signé entre l'Euratom, l'Université Technique d'Aix-la-Chapelle et le Centre de Recherches de Jûlich pour l'étude des rapports entre la filière HTR et la production d'hydrogène par dissociation thermochimique.

On doit par contre noter que les USA continuent d'étudier, comme suite au HTR en cours de large réalisation commerciale, un HTR 2 où, à l'intérieur même du réacteur par réformage du CH_4 par la vapeur, on obtiendrait un mélange de CO et H_2. Leurs gisements de charbon à bon marché et leurs énormes efforts sur la gazéification et la liquéfaction du charbon les écartent en fait, malgré les sollicitations des universitaires, de ce grand mouvement d'enthousiasme qui, en Europe et au Japon, se dirige vers l'hydrogène. En face de la stratégie "Nucléaire-Hydrogène", ils construiraient volontiers celle "Charbon-Combustible synthétique", méthanol par exemple.

III. L'hydrogène vecteur d'énergie

Nous avons esquissé, en définissant la solution "tout nucléaire", une économie de l'énergie avec deux structures d'accueil parallèles: l'électricité et l'hydrogène, ce dernier produit à bon marché en grande masse grâce à la chaleur nucléaire à partir de l'eau. Son introduction pourrait être progressive, car les installations actuelles de transport, de stockage, de distribution peuvent utiliser dès aujourd'hui, sans aucune modification, 10 à 15% d'hydrogène. Son transport massif ressemblerait au transport actuel du gaz naturel et ne pose aucun problème; il y a déjà un réseau en Allemagne Fédérale de 300 km de longueur. Il serait de cinq à dix fois moins cher que celui de l'électricité. Le stockage par réservoirs souterrains de plusieurs milliards de mètres cubes se ferait en utilisant des gisements de gaz naturel actuellement épuisés.

La diversité des usages de l'hydrogène est extraordinaire. Rien ou presque ne lui échappe. Ses usages comme réducteur en sidérurgie ou en chimie sont bien connus. Dès aujourd'hui 20 millions de tonnes sont consommées dans le monde.

M. GREGORY, de l'Institute of Gas Technology (USA), institution très vénérable, pense à un délai de vingt ans avant la mise au point industrielle. C'est très suffisant, mais il ne faut plus perdre de temps et la France doit coordonner ses efforts actuellement un peu dispersés.

IV. Les problèmes d'environnement

Cette solution "tout nucléaire" est presque parfaite en ce qui concerne les problèmes de ressources et d'autarcie. Elle peut évidemment échouer ou réussir pour des raisons techniques et économiques, d'où la nécessité de "solutions lointaines", mais en cas de succès le grand problème est de connaitre les limites que pourrait lui imposer l'environnement. Nous ne visons pas ici les problèmes climatologiques car ils sont communs à toutes les solutions. Nous ne visons pas non plus les dangers de radioactivité dans l'air ou par les effluents, car ils ne sont pas sérieux. Certes personne ne peut garantir qu'il n'y aura pas un jour un

accident nucléaire et il faut être bien conscient des conséquences, mais l'homme vit depuis Adam et Eve dans le danger et celui-là nous parait beaucoup moins probable et beaucoup plus faible que les divers "actes de Dieu": tremblements de terre, raz de marée, typhons, etc. Le problème réel est dans la prolifération éventuelle du nucléaire car, comme l'écrivait Alfven, prix Nobel de physique 1970, dans une communication à la deuxième conférence de Pugwash (automne 1973), "un ou plusieurs réacteurs soigneusement contrôlés ne peuvent être une menace écologique sérieuse, mais s'ils se répandent de façon quasi illimitée tout change".

Il ne s'agit pas là d'une simple multiplication, même par un grand nombre de petits risques, mais d'un véritable risque nouveau dû à la nature profonde de l'homme.

Le plutonium est un poison, même pour un millième de milligramme, or l'ensemble des surrégénérateurs d'un pays comme la France dans une solution "tout nucléaire" mettra des tonnes en jeu par an. Toutes les précautions possibles seront certainement prises dans les processus de récupération ou dans les accidents inévitables de transports, mais que ne peut-on pas imaginer dans notre monde où la violence sera de plus en plus une tentation?

L'homme est-il capable de se dominer quand il a le pouvoir au bout du geste? Tous les problèmes de stockage, préparation du combustible, retraitement, en changeant d'ordre de grandeur changeront donc de nature.

De même en matière de déchets, les précautions à prendre devront être poursuivies peut être pendant des milliers d'années, or l'homme ne s'est jamais trouvé devant des responsabilités d'une telle durée et personne ne peut dire aujourd'hui comment il les assumera. Certes il y a l'espoir de transformer les déchets en produits à vie plus courte par des traitements radioactifs et il faudrait certainement en pousser l'étude plus énergiquement que cela a été fait jusqu'ici.

La solution "tout nucléaire" suppose des humains policés, disciplinés, heureux de leur sort, etc. Ceci est impossible, aussi son extension aura une limite due à la nature de l'homme et nous ne la connaissons pas. Aujourd'hui nous en sommes très loin!

DEUXIEME CHAPITRE: TECHNIQUES ET SOURCES SECONDAIRES

Il s'agit de sources d'énergie déjà mûres techniquement et capable de jouer dès aujourd'hui, localement, un rôle intéressant: énergie marémotrice en premier lieu, peut-être l'énergie thermique des mers ou celle des vents, celle de la houle appraissant pour le moment inutilisable.

Il faut citer aussi certaines filières de réacteurs non exploitées qui pourraient, dans certains cas favorables, trouver un débouché par leur intérêt pour l'environnement, mais qui se heurteront pour la plupart à l'impossibilité de réunir les sommes immenses qu'exige toujours toute recherche nucléaire (sels fondus, eau lourde refroidie par un liquide organique, sodium, graphite-gaz, etc.).

Il ne faut pas négliger les techniques nouvelles de conversion, transport et stockage. On saura dans quelques années au plus si les efforts actuels en matière de piles industrielles à combustible à grande puissance (26 MWe) seront couronnés de succès, car les électriciens des USA viennent de décider de quadrupler leurs efforts actuels.

L'usage de cycles de tête couplés avec des sources d'énergie primaire à haute température (1000° et au dessus) pourrait diminuer de moitié les rejets thermiques ce qui parait capital.

Certaines méthodes nouvelles de stockage par changement de phase peuvent aussi être utilisées avec profit.

Il ne faut pas oublier enfin les explosions nucléaires pacifiques en cours d'introduction industrielle.

TROISIEME CHAPITRE: LES SOLUTIONS LOINTAINES

Il ne faut pas compter sur les flux d'énergie qui nous entourent (énergie solaire mise à part) car lorsqu'on calcule leur importance on trouve que leur puissance à l'échelle de la terre est du même ordre de grandeur que celle transformée aujourd'hui par l'homme pour son propre usage à l'aide des combustibles fossiles, soit quelques milliards de kilowatts.

Nous avons ainsi passé un jour en revue les cyclones, la foudre, les tremblements de terre, les éruptions volcaniques, le flux de chaleur provenant par conduction des couches profondes de la terre, etc. Leur utilisation demanderait un effort technologique sans doute bien supérieur à celui que l'homme vient de faire pour l'atome et soulagerait peu ses problèmes.

Pour l'essentiel, il reste les trois grandes sources connues aujourd'hui: énergie solaire, énergie géothermique, fusion nucléaire.

QUATRIEME CHAPITRE: PROBLEMES CLIMATOLOGIQUES

L'action sur le climat des rejets thermiques a fait l'objet depuis quelques années d'études globales de plus en plus approfondies sans qu'aucun résultat précis ait pu être atteint. Le sujet est très difficile car de nombreuses contre-réactions interviennent et les climats sont sans doute par nature instables sans que l'intervention de l'homme soit nécessaire.

On est aujourd'hui à peu près d'accord sur le fait qu'à l'échelle mondiale il n'y a rien à craindre d'ici longtemps, probablement plus de cent ans. Mais l'influence éventuelle sur les micro-climats des rejets thermiques locaux apparait beaucoup plus grave et constitue à notre avis le problème essentiel posé par la croissance économique.

Les grandes options en matière énergétique du XXI^{e} siècle sont claires. Surrégénération et hydrogène permettront sans doute de construire pour l'an 2000 une solution "tout nucléaire" résolvant les problèmes de ressources et d'autarcie et nous délivrant du joug des combustibles fossiles. En cas de retard ou d'échec, des "solutions lointaines": énergie solaire, énergie géothermique, fusion nucléaire surtout devraient, si nous faisons un effort suffisant, être prêtes à prendre la relève pour une durée presque illimitée.

Mais les difficultés à surmonter ne sont pas minces.

- D'abord des problèmes techniques, il ne s'agit pas de simple substitution d'un combustible à l'autre; rappelons-nous la surrégénération, phénomène extraordinaire qui va faire du combustible nucléaire un simple sous-produit de l'activité industrielle; l'hydrogène nouveau vecteur énergétique tiré simplement de l'eau et s'introduisant peu à peu en parallèle avec l'électricité qui modifiera de ce fait toute notre vie domestique et toutes les structures industrielles; la fusion nucléaire qui exigera de porter la matière à cent millions de degrés et où les processus industriels correspondants seront formés de micro-explosions de durée inférieure au milliardième de seconde.
- Ensuite des problèmes humains. Certes, ces techniques nouvelles atténuent parfois

considérablement les défauts des centrales actuelles vis-à-vis de l'environnement, pollution de l'air et de l'eau; elles sont donc dans le sens de ce que réclame aujourd'hui l'homme. Mais celui-ci a reporté sur l'énergie nucléaire sa terreur de la bombe et ne se dégage que lentement de ses phantasmes. Un accident les raviverait et créerait certainement des situations de rejets ralentissant la solution "tout nucléaire". Indépendamment de cela, la prolifération illimitée des réacteurs nucléaires créera des risques d'un type tout nouveau; la plus petite parcelle de plutonium est un poison mortel, la surrégénération en mettra en jeu par an des tonnes réparties dans des centaines de sites, circulant sur les routes et les voies ferrées. Que ne peut-on craindre dans un monde où la violence continue à régner en maitre? Autre problème, la conservation des déchets devra être assurée pendant des centaines, peut-être des milliers d'années, l'homme n'a jamais raisonné sur de telles durées. Peut-il en prendre la responsabilité? Une certaine limite interviendra pour la solution "tout nucléaire" entraînant le passage aux "solutions lointaines".

— Enfin des problèmes de climatologie, la terre devenant peu à peu à l'échelle de l'homme. Les problèmes de micro-climats apporteront pour toutes les solutions énergétiques, quelles qu'elles soient, une limite à la puissance installée sur un site et fixeront ainsi un maximum à notre croissance économique. S'il nous parait difficile, comme à tous les ingénieurs, de croire qu'une croissance économique raisonnable puisse être stoppée par épuisement des matières premières ou ensevelissement sous la pollution, nous continuons à croire, peut-être naïvement, à la puissance des sciences et techniques pour résoudre les problèmes. Mais l'homme arrive indiscutablement aujourd'hui au moment où, pour les problèmes énergétiques dans certains lieux, il dépasse la nature. Pour la première fois, il rencontre un obstacle dont il ne sait pas s'il pourra un jour le contourner ou l'abattre.

Il nous faut, avant de terminer, faire la réserve d'usage. D'ici à trente ans des découvertes absolument imprévues feront certainement irruption et nous n'en avons pas tenu compte, ce qui semble rendre parfaitement inutile tout cet exposé. Chacun sait que les échanges d'énergie dans le monde stellaire sont prodigieux. Par exemple, pour certains astronomes en une seconde un "quasar" émet autant d'énergie que l'homme pourra en consommer au rythme actuel pendant des milliards d'années.

Ceci est vrai, mais il est aussi vrai qu'avec l'inertie extraordinaire des problèmes énergétiques, les découvertes de fin de siècle n'influenceront que peu les premières décennies du XXI^{e} siècle.

Chapter I

CONSUMPTION OF ENERGY AFTER 2000

Président: T. LEARDINI

CONTENTS

BESOINS D'ENERGIE EN 2000

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Il y a peu encore, la plupart des experts s'accordaient pour estimer que la consommation d'énergie du monde à la fin de ce siècle pourrait être de l'ordre de 20 milliards de tonnes d'équivalent pétrole, quatre fois celle de 1970. Mais depuis trois ans le secteur de l'énergie a connu diverses secousses: l'alerte aux atteintes à l'environnement (cf. les mouvements aux Etats-Unis et au Japon), la dénonciation du pillage des ressources fossiles non renouvelables (cf. le rapport au club de Rome), la dernière crise pétrolière et le quadruplement des prix du brut qui en résulte; ces secousses conduisent-elles à remettre en cause les perspectives à long terme de consommation d'énergie? Il ne le semble pas.

— les atteintes à l'environnement que l'on peut craindre d'une consommation accrue et du développement du nucléaire, semblent pouvoir être maîtrisées et contenues à un niveau acceptable au prix de recherches technologiques, d'adaptations des systèmes de production et d'un coût économique à la fois supportable et de mieux en mieux accepté,

— le développement des énergies nucléaires et de leurs vecteurs, électricité et hydrogène, et l'ampleur des réserves fossiles, notamment en charbon, suffisent à montrer qu'il n'y a pas de risque d'insuffisance physique de ressources énergétiques pour l'humanité,

— le relèvement des prix des énergies fossiles ne fait qu'anticiper, avec quelques excès, sur une évolution économique qui était en tout état de cause inéluctable à terme plus éloigné, lorsqu'il serait apparu indispensable de développer des ressources de substitution à celles, supercompétitives, auxquelles le monde a eu recours depuis 20 ans. L'anticipation dans le développement des ressources de substitution qui en résultera ira d'ailleurs dans le sens d'une garantie accrue à l'égard de tout risque de pénurie.

— enfin, l'évolution des ressources avec le remplacement des énergies fossiles par le nucléaire, la géothermie, le solaire, annonce un retour progressif vers une plus grande indépendance énergétique des états et une relative autarcie des grandes régions géographiques.

Si les péripéties énergétiques actuelles ne modifient pas radicalement les perspectives à très long terme, en coût comme en disponibilité, comment se fait-il que se dégage une tendance à réduire ces prévisions de consommation. Sans doute le cheminement d'ici 2000 va-t-il se trouver transformé, surtout à court et moyen terme, par les nouvelles données de

l'économie énergétique, dans le sens d'une anticipation et la situation 2000 s'en trouvera bien entendu modifiée; mais l'explication ne suffit pas.

Il apparait surtout que l'on prend plus clairement conscience d'une série de facteurs qui, pour la plupart, devraient jouer dans le sens d'une réduction de la croissance des besoins en énergie, du moins dans les pays industrialisés qui aujourd'hui représentent 85% de la consommation mondiale d'énergie.

Le quadruplement de la demande entre 1970 et 2000 représentait une extrapolation des tendances observées depuis 25 ans: le doublement en 15 ans: ce n'est pas là une loi de la nature. Au début du siècle, il a fallu 25 ans, de 1900 à 1925, pour voir doubler la consommation mondiale et celle-ci n'a guère augmenté entre 1929 et 1945. Quelle est la bonne tendance pour ce dernier quart de siècle?

Parmi les facteurs susceptibles d'infléchir la croissance énergétique, trois sont à souligner:

— l'évolution des coûts de l'énergie
— la saturation de certains besoins
— la croissance économique des prochaines décennies.

1. L'EVOLUTION DES COUTS DE L'ENERGIE

De 1950 à 1970 et plus spécialement dans les années 60, les coûts de l'énergie ont régulièrement diminué, en monnaie constante: en France de 1960 à 1970, ils ont baissé de 30 à 40% pour les hydrocarbures.

Comme il a été indiqué antérieurement, les prix actuels sont certainement plus représentatifs de l'économie énergétique à long terme qu'ils anticipent. Le parc des appareils et des procédés utilisant l'énergie se trouve ainsi porté, brutalement, très loin de son optimum économique, qu'il faudra des années, sinon des décennies pour retrouver mais qui induira, pour une même production ou une même satisfaction, des quantités d'énergie bien moindres. Pour prendre l'exemple de chauffage des logements, les normes d'isolation correspondant au nouvel optimum économique, et qui ont été rendues obligatoires en France pour les constructions neuves, conduisent, à conditions de confort égales, sinon accrues sur le plan phonique et de la régulation, à des consommations d'énergie réduites de près de moitié par rapport aux errements antérieurs; mais il faudra des décennies pour renouveler tout le parc; moitié des logements qui seront occupés en 2000 sont dejà construits.

Ce qui est vrai du chauffage des logements et plus généralement de tous les locaux, l'est certes aussi de la plupart des installations industrielles. Cette constatation et l'ampleur de la plage dans laquelle peut varier l'apport d'énergie pour un effet donné ne font d'ailleurs que traduire la part extraordinairement faible de l'énergie qui est effectivement consommée, c'est-à-dire transformée: ainsi du chauffage où cette part est nulle, où l'énergie ne sert qu'a maintenir un état donné de température, en alimentant des pertes thermiques; de même de l'énergie mécanique qui pour une large part sert à faire travailler des forces de frottement pour produires de la chaleur.

L'arbitrage à faire dans chaque cas est économique, le nouvel optimum ne sera atteint que dans des décennies, mais il pourrait bien correspondre à des consommations plus faibles d'un tiers, voire davantage, à ce qu'elles auraient été aux coûts de l'énergie de 1970.

Ce qui importe aujourd'hui c'est de se rapprocher le plus rapidement possible de cet optimum, c'est bien le principe des campagnes contre "le gaspillage", pour les économies

d'énergie, pour la conservation de l'énergie, qui sont entreprises dans nos pays, et dont l'effet sera un infléchissement sensible et durable à moyen terme des taux de croissance des besoins, difficile d'ailleurs à estimer; on peut noter seulement que —30% d'ici 2000 correspond à une réduction de 1,5% du taux de croissance moyen d'ici 2000.

2. LA SATURATION DE CERTAINS BESOINS

Les économistes relient souvent la croissance des besoins d'énergie à des grandeurs économiques comme le PNB, la PIB, la valeur ajoutée industrielle, selon des formules plus ou moins simples et qui font apparaître des élasticités généralement proches de l'unité; ce qui n'est pas critiquable dès lors que l'on admet que cette élasticité n'a pas de raison de demeurer constante.

Lorsqu'on analyse la croissance des consommations finales d'énergie en France entre 1960 et 1970, on constate que:

— le total a cru de 95%, mais
— le secteur domestique a augmenté sa consommation de 150%
— les transports de 120%
— et l'industrie seulement de 55%.

C'est donc la demande des ménages, et du tertiaire, qui a été la plus dynamique dans la croissance énergétique. Résultat en premier lieu d'un équipement intensif et rapide des logements neufs et anciens en moyens de chauffage et d'un relèvement des températures intérieures; au recensement de 1954, 10% des logements français avaient un chauffage central, plus de 50% aujourd'hui; même si l'on est encore loin du terme, moitié du chemin a été fait, un ralentissement est probable à court terme, la saturation certaine avant l'an 2000. On pourrait tenir le même langage à propos de l'équipement du foyer en appareils gros consommateurs d'énergie, c'est-à-dire de chaleur: production d'eau chaude, machines à laver. Il n'est guère que la climatisation qui puisse prendre la relève.

Autre secteur de pointe celui des transports, dans lequel la route représente les 2/3 de la consommation, là aussi le ralentissement apparaît certain à terme proche, dès lors que la proportion des ménages équipés de véhicules automobiles est passé de 30% en 1960 à près de 70% aujourd'hui et que l'exemple des USA indique que la saturation se situe aux alentours de 90%.

Une croissance des besoins en énergie des ménages vers l'an 2000 à peine supérieure à celle de la population comme c'est déjà le cas pour les besoins alimentaires, n'est nullement invraisemblable.

Quant à l'industrie il suffira de noter que l'élasticité énergie/production a été de l'ordre de 0,6 sur cette période.

3. LA CROISSANCE ECONOMIQUE

Depuis 20 ans la croissance des besoins d'énergie a été le corollaire d'une croissance de l'économie, et des niveaux de vie, extrêmement rapide dans les pays industrialisés.

Il n'est pas évident, sans même faire l'hypothèse d'une révolution dans l'attitude à l'égard de la croissance, du style de croissance zéro, que celle-ci puisse se poursuivre au même rythme. Elle a, en effet, été soutenue par une croissance forte et régulière de la productivité

du travail, supérieure à la tendance séculaire, par des arbitrages plus favorables à l'augmentation de la consommation qu'à la réduction des temps de travail, par une croissance de la population active notamment non agricole qui semble devoir à terme se ralentir. Quelques esquisses faites à horizon 1990 pour la France, prenant en compte la seule incidence de l'évolution des facteurs de production, montrent que la taux annuel de croissance pourrait alors avoir diminué de 0,5 à 1,5 point.

En outre, le type actuel de Croissance, dont le moteur est le développement industriel, ou la consommation de biens matériels, est par lui-même très incitateur à la consommation d'energie. Il est vraisemblable que cette croissance, supposée se poursuivre, fera une place de plus en plus large à des activités exigeant un faible substrat matériel (prestations de service, machines à information etc. . . .) et ayant donc un plus faible contenu énergétique.

Enfin, la croissance de la demande de transports ne se trouvera-t-elle pas freinée par le développement de moyens de téléinformation, vidéophone, téleconférence et par celui des transports en commun? Ceci pose, d'une façon plus générale, la question des modes de vie qui prévaudront au début du XXI^{e} siècle et de leurs conséquences sur la consommation d'énergie.

En bref, il apparaît que, dans les pays industrialisés, le relèvement des prix de l'énergie, la saturation progressive de certains besoins, une croissance moins rapide et plus orientée vers des activités tertiaires, devraient se conjuguer pour réduire dans de fortes proportions, et de façon durable, la croissance des besoins en énergie; à fortiori, si survenait dans ce dernier quart de siècle des crises économiques ou politiques ou s'il connaissait la remise en cause radicale, que réclament certains, de la croissance.

Même si l'on exclut ces dernières éventualités, explorant un scénario "sans surprise", il n'en demeure pas moins impossible de quantifier ce que pourrait être la consommation énergétique de l'an 2000 des pays développés. Qu'il s'agisse d'élasticité de la demande aux prix, de niveaux de saturation des besoins, de relation entre croissance et besoins d'énergie, la science économique ne nous apporte guère, hélas!, ni modes d'analyse, ni instruments de prévision fiables. A sa décharge la qualité insuffisante des statistiques économiques ou énergétiques.

Aussi dire que en fin de siècle cette consommation ne sera guère plus du double de la consommation actuelle, relève moins de la prévision que de l'intuition.

Mais cette analyse ne vaut que pour les pays industrialisés. Saturation des besoins, ralentissement structurel de la croissance sont des mécanismes qui ne joueront pas d'ici le début du XXI^{e} siècle, dans les pays en voie de développement.

Sans doute ces pays ne représentent-ils aujourd'hui qu'une part faible de la consommation mondiale d'énergie quelque 15%. Par contre, il n'est pas exclu que dès le début du XXI^{e} siècle ils occupent une place déterminante dans l'économie énergétique, non plus seulement comme producteurs, mais comme consommateurs.

A titre d'illustration (ce n'est pas une prévision), supposons que se poursuive la croissance des besoins en énergie de ces pays au même rythme que pendant la décennie 60; en 2000 ils pourraient représenter près de 40% de la consommation mondiale d'énergie et quelque 60% de son augmentation. Et pourtant leur consommation par tête n'atteindrait pas la moitié de celle de l'Européen d'aujourd'hui.

Mais ceci n'est qu'une image, peut être trop optimiste, car l'incertitude essentielle tient

dans le rythme et le type de développement économique que connaîtront ces pays au cours des prochaines décennies.

Il faudrait enfin évoquer le problème des formes sous lesquelles l'énergie sera consommée au début du XXI^e siècle, c'est-à-dire des vecteurs énergétiques eux-mêmes liés aux énergies primaires qui seront alors mobilisées. La situation sera alors sans doute profondément différente. Qu'il suffise de dire que le développement du nucléaire implique certainement une forte pénétration de l'électricité dont la place dans la consommation, de moins de 25% aujourd'hui, pourrait dépasser alors 50%, et également, mais à terme plus éloigné, l'introduction du vecteur hydrogène.

Si le XXI^e siècle est celui du nucléaire, il sera sans doute, à la consommation, celui de l'électricité et de l'hydrogène.

On pourra s'étonner de ce que cet exposé se soit limité à une approche exclusivement économique, que l'on ait cherché à définir une consommation d'énergie comme résultat d'une demande s'exprimant en économie de marché, donc en fonction des prix, mais sans autre contrainte quantitative.

Il ne pouvait en être autrement dès lors que l'on admettait qu'il n'y a pas risque de pénurie et que les effets sur l'environnement pourront être maîtrisés. S'il en est bien ainsi, la crise énergétique n'oblige pas, par elle-même, à une remise en cause de nos modèles de développement. D'autres préoccupations, politiques, morales, idéologiques, y obligeront peut-être; elles sont d'une autre nature; pourtant peut-être la crise de l'énergie aura-t-elle aidé à en prendre conscience.

SUMMARY

If there does not seem to be any reason to fear a shortage of energy in the long term, if the impact of energy production on environment may be mastered, if the recent price rise is nothing but the anticipation of an unavoidable trend, it still remains that several factors work towards a slowing down of the rate of increase of demand.

- higher energy prices urge to search for processes with lower energy costs
- the household needs, especially in petrol and for heating, are nearing saturation levels
- economic growth should gradually slow down leaving at the same time priority to activities consuming less raw materials and less energy

The effect of these various factors is hard to put in figure, yet a doubling of energy needs between 1975 and 2000 does not appear unrealistic.

BESOINS D'ENERGIE APRES L'AN 2000 DU POINT DE VUE DES PAYS EN VOIE DE DEVELOPPEMENT

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Depuis les civilisations les plus reculées l'homme a toujours accordé une importance particulière à l'énergie. Il a commencé par lui attribuer une puissance divine, se rendant compte intuitivement qu'elle était à l'origine de la vie et qu'elle engendrait les transformations de son environnement. Aujourd'hui l'homme considère l'énergie comme l'une des premières nécessités, une relation étroite s'est établie entre le progrès économique et l'énergie disponible d'un pays. Il suffit de comparer la consommation d'énergie d'un pays par habitant à son revenu national brut pour se convaincre de la véracité de cette étroite relation. Le kilowatt heure d'électricité consommé par habitant est devenu une sorte d'unité servant à mesurer la prospérité nationale c'est aussi un indicateur de développement. Il convient surtout de souligner que la majorité de la population mondiale n'a pas encore d'électricité; à titre d'exemple choisissons le cas de l'Asie où vit près de la moitié de la population du globe, la production d'électricité sur ce continent ne représente que le dixième de la production mondiale.

Examinons encore quelques chiffres se rapportant à la situation énergétique dans le monde pour l'année 1970. Nous enregistrons que l'énergie produite dans le monde entier est de l'ordre de 50 billions de kilowatt heure de chaleur, il convient d'ajouter tout de suite que les pays en voie de développement ont consommé moins de 15% de ce total. Cependant on prévoit que pour ces pays la consommation augmentera à un taux beaucoup plus rapide que celui du produit national brut. En effet, si on se base sur le rapport de 1,6 pour l'élasticité de la demande en énergie par habitant par rapport au revenu, il apparaîtra alors que le total des besoins en énergie pour les pays en voie de développement s'accroîtra au rythme d'environ 8,4% par an si le produit national brut augmente de 6% en moyenne; ceci en se plaçant dans l'hypothèse d'un taux de croissance de la population de 2% par an pour les pays en voie de développement. Ces chiffres servent de base pour la plupart des études effectuées par les organismes des Nations Unies.

La consommation mondiale pour l'énergie électrique est évaluée à 4900 millions kWh dont 12% reviennent aux pays en voie de développement; pour cette forme d'énergie le taux d' augmentation annuel est de l'ordre de 8%.

A partir de ces données des prévisions à long terme laissent supposer que la consommation d'énergie après l'an 2000 sera multipliée par un facteur 4 par rapport à celle de 1970. Il

semble qui si on tient compte de certaines améliorations vivement souhaitées de la situation économique et du niveau de vie des pays en voie de développement ainsi que de l'augmentation de la population mondiale la consommation mondiale sera multipliée par un facteur égal à 5 au moins pour après l'an 2000.

Ainsi ayant fixé des valeurs aux bornes pour la période 1970–après 2000 les besoins cumulés d'énergie pour cette période s'avèrent appréciables comparés aux évaluations des réserves des ressources énergétiques actuellement exploitées (charbon, gaz, pétrole, potentiel hydroélectrique, uranium enrichi). Il est manifeste que si on veut éviter au monde le risque d'une pénurie réelle et une atteinte grave à l'environnement une stratégie de l'énergie doit être définie et élaborée à l'échelon international.

La méthode de l'action à entreprendre peut s'inscrire dans le cadre de trois objectifs principaux:

1°) Analyser et étudier les possibilités d'améliorer l'efficacité des ressources énergétiques actuelles en veillant à limiter au maximum le gaspillage de précieuses ressources énergétiques non renouvelables.
2°) Etablir un programme de recherche portant sur l'étude de nouvelles sources d'énergie.
3°) L'étude de la rentabilité économique de chaque ressource d'énergie actuelle ou future doit nécessairement tenir compte du facteur environnement.

Permettez-moi de détailler davantage ces trois points. Selon une source américaine la valeur énergétique des déchets engendrés chaque année aux Etats-Unis représente l'équivalent de 270 millions de barils de combustibles à faible teneur sulfurique.

La technologie actuelle des transports offre un exemple flagrant de faibles rendements énergétiques: 15% pour le moteur à combustion interne.

Les techniques protectives ou isolantes peuvent réduire considérablement les besoins énergétiques des unités d'habitation etc.

Les exemples sont nombreux pour lesquels une limitation du gaspillage et j'insiste sur le mot, peut constituer un domaine d'étude.

Il importe que l'opinion publique mondiale ne considère pas les ressources naturelles énergétiques et plus spécialement les combustibles fossiles comme inépuisables. Ces produits ou plus exactement les réserves de ces produits ne sauraient être reconstituées, il convient alors de conserver une partie de ses réserves de pétrole, de gaz et de charbon pour les besoins de la chimie.

L'analyse du diagramme du flux d'énergie nous montre que si pour 1970 la partie de l'énergie perdue après conversion est du même ordre de grandeur que l'énergie utilisée, pour 1980 la situation serait plus déficiente dans la mesure où le rendement a tendance à diminuer: c'est là l'une des conclusions des travaux de la commission parlementaire américaine chargée des questions concernant l'énergie atomique le "Joint Committee on Atomic Energy".

Il est donc plus que vraisemblable que les hydrocarbures fossiles ne pourront plus répondre à la demande d'énergie après l'an 2000 et qu'il est urgent de mettre au point un vaste programme de recherche portant sur la découverte et l'exploitation de nouvelles sources d'énergie qui seront opérationnelles dans la meilleure hypothèse à la fin du XX[e] siècle.

Quelles peuvent être ces nouvelles sources?

Dans le domaine nucléaire deux types de réacteurs renferment de grandes promesses pour l'avenir et pourraient constituer une solution aux problèmes énergétiques.

Le réacteur surrégénérateur qui multiplie par un facteur 100 la valeur énergétique de l'ur-

anium grâce à la couche fertile qui entoure la matière fissile, en outre ce réacteur aurait le mérite de présenter d'autres avantages tel que meilleur rendement, moins de déchets radioactifs etc.

Le réacteur thermonucléaire: plus de 200 expériences sont en cours en différents points du globe, les progrès sont certes lents mais grâce aux développements technologiques on peut espérer que la fusion soit bientôt maitrisée.

Le passage par l'énergie nucléaire pour la production d'électricité paraît inévitable et il convient pour les pays en voie de développement de s'y préparer par l'acquisition d'une certaine expérience en technologie nucléaire. L'installation d'une centrale nucléoélectrique ne relève plus actuellement du prestige.

Les installations utilisant l'énergie des marées ou l'énergie géothermiques fonctionnent déjà dans certains pays mais leur emplacement est soumis à des conditions très spécifiques qui limitent grandement leur généralisation. Il est par ailleur très avantageux d'exploiter ces formes d'énergie pour lesquelles l'infrastructure ne nécessite pas de grands investissements.

On estime par ailleurs que le potentiel hydroélectrique mondial est d'environ 3 millions MW dont moins de 10% ont été exploités principalement par les pays nantis, alors que la plus grande partie de l'énergie hydroélectrique non encore exploitée se trouve dans les pays en voie de développement.

L'énergie solaire constituera je présume une des solutions énergétique de l'avenir pour les pays en voie de développement Certes elle présente deux défauts: se répartir avec une densité très diluée d'une part et présenter un aspect irrégulier d'autre part. Mais malgrè ces inconvénients et l'albado elle offre des avantages de premier ordre.

1°) Elle se manifeste avec une durée de vie illimitée.
2°) Elle ne présente pas de déchets, pas de polluents.
3°) Elle supprime tous les monopoles et les problèmes complexes d'autarcie.

Pour terminer cette liste ajoutons que la mise au point d'une pile à combustible économiquement rentable pourrait être introduite dans les régions rurales des pays en voie de développement où aucun réseau électrique ne pénètre.

Pour conclure on peut espérer que l'innovation technique et l'effort de création des chercheurs joueront un rôle essentiel pour détendre le marché de l'approvisionnement actuel en énergie et pour établir entre les pays importateurs et les pays exportateurs une coopération économique, scientifique et technique dans l'intérêt de l'humanité toute entière.

L'AVENIR A LONG TERME DE L'ELECTRICITE EN FRANCE

R. Ginocchio

Directeur à la Direction Générale d'EDF

L'objet de cette communication est de présenter une étude prospective en choisissant un cas particulier: l'énergie électrique en France à la fin du premier quart du XXI^e siècle.

Les données de base de cette communication sont fournies par les résultats des études entreprises par Electricité de France à ce sujet.

Nous présenterons tout d'abord un scénario de la France aux environs de l'année 2025, puis nous chercherons à évaluer les besoins en électricité, enfin nous indiquerons les moyens de production, transport et distribution de l'électricité qui paraissent devoir être utilisés pour faire face à ces besoins.

LA FRANCE EN 2025

L'estimation des besoins en électricité à la fin du premier quart du XXI^e siècle nécessite en premier lieu la formulation d'hypothèses sur ce que sera la France à cette époque: c'est ce tableau que nous allons essayer de brosser rapidement.

Rappelons tout d'abord les changements profonds intervenus ces dernières années dans les facteurs qui conditionnent la demande, la croissance et les objectifs de celle-ci.

L'épuisement possible des matières premières, qui se fait sentir en premier lieu par leur renchérissement, et des ressources naturelles, impose des *limites au rythme de croissance*: certes, le progrès scientifique et technique offre toujours des possibilités d'adaptation, néanmoins une croissance durablement exponentielle dans un monde fini apparaît désormais impossible.

Les inégalités et les frustrations engendrées par la croissance en elle-même, non seulement à l'intérieur d'un pays, mais surtout, beaucoup plus gravement, entre les pays développés et le Tiers Monde, imposent *un nouvel objectif* à la croissance: il ne s'agit plus seulement de créer des richesses, mais d'assurer une convenable redistribution de celles-ci au niveau mondial.

L'économie des ressources naturelles et une meilleure répartition des fruits de l'expansion devront ainsi conditionner la croissance future.

Dans un monde où une nouvelle division du travail serait réalisée, les industries lourdes s'implanteront de préférence dans les pays moins développés, mais plus riches en main-d'œuvre, en ressources naturelles et en espace, leur permettant ainsi de participer à la

croissance et d'en bénéficier; la France, comme tous les pays développés, sera de ce fait conduite à spécialiser son économie dans les industries légères à haute valeur ajoutée et dans les activités de service.

Dans un monde où la croissance sera sans doute ralentie, mais non arrêtée (la croissance zéro paraît en effet difficilement compatible avec la lutte contre la pauvreté), la France, comme les autres pays développés, connaîtra un rythme de croissance économique légèrement inférieur à celui de l'ensemble du monde, du fait de la spécialisation de son économie dans les secteurs à faible productivité (activités de service).

Les principaux traits du scénario adopté pour la France de 2025 sont les suivants:

1) Nous avons retenu l'hypothèse d'un développement démographique s'effectuant à un taux décroissant: 0,9% entre 1970 et 1985, 0,8% entre 1985 et 2000, et 0,6% entre 2000 et 2025. La population française atteindra ainsi 75 millions d'habitants en 2025.

2) L'urbanisation aura été réalisée dans les dernières décennées du XX^{e} siècle en grande partie au profit des *villes moyennes* où se sont installé les industries légères ou des activités tertiaires; un développement important des télécommunications est le corollaire de ce type d'organisation.

3) L'accroissement des loisirs journaliers et hebdomadaires favorisera le rôle socio-culturel de ces villes, lieux de rencontre, centres de services et de distractions pour toute la population de leur zone d'influence.

4) Les activités diverses de la vie courante (transports, travaux ménagers, surveillance des enfants) sont l'objet d'organisations collectives.

LES BESOINS EN ELECTRICITE

Le ralentissement du rythme de croissance démographique et économique, l'implantation dans le Tiers Monde des industries lourdes, l'aménagement décentralisé du territoire, l'organisation collective de nombreuses activités de la vie courante sont autant d'éléments défavorables à une croissance énergétique à un taux élevé; par ailleurs, l'héritage des dernières décennies du XX^{e} siècle, durant lesquelles l'élévation du prix des hydrocarbures aura créé des habitudes d'économie d'énergie (isolation thermique des locaux, transformation des techniques industrielles), agira dans le même sens.

En sens inverse, pourront jouer le développement des télécommunications et surtout celui des industries de recyclage des déchets, de dépollution et de traitement de l'eau de mer.

Les études faites en tenant compte de ces évolutions conduisent à adopter, pour 2025, une consommation d'énergie par tête de l'ordre de grandeur de 12 tec, niveau voisin de celui atteint aux Etats-Unis actuellement. Il en résultera, pour une population de 75 millions d'habitants, une consommation totale de 900 millions de tec, qui correspond à une progression annuelle moyenne de la consommation d'énergie de 1,5%, en net ralentissement par rapport au rythme prévu entre 1985 et la fin du siècle (3,3%).

La substitution de l'électricité aux autres formes d'énergie aura été réalisée progressivement dans tous les domaines qui lui sont ouverts: usages domestiques, usages industriels et transport (le véhicule électrique à accumulateurs sera alors le principal moyen de transport urbain). En 2025, les 2/3 des besoins en énergie seront ainsi couverts par l'électricité, contre la moitié en 2000. Les hydrocarbures, qui auront perdu définitivement leur prépondérance dans le secteur énergétique, seront désormais utilisés surtout comme des matières premières

industrielles et non plus comme des combustibles; quant au charbon, il aura pratiquement disparu du bilan énergétique depuis la fin du XX^e siècle.

Un autre facteur influencera le développement de la consommation d'électricité durant le premier quart du XXI^e siècle:

C'est l'apparition de *l'hydrogène*, en tant que vecteur d'énergie: celui-ce remplacera en partie l'électricité pour réaliser les transports massifs d'énergie et pour assurer des stockages importants à un prix relativement bas. Il pourra par ailleurs être utilisé directement par les industriels pour des usages thermiques parfaitement non polluants ou être employé comme combustible dans les transports.

LES MOYENS DE PRODUCTION DE L'ELECTRICITE

L'énergie nucléaire assurera, au cours des premières décennies du siècle prochain, 90% de la production d'électricité. Comment sera constitué la part des centrales, produisant cette énergie?

Les surrégénérateurs se substitueront progressivement aux centrales nucléaires classiques dès la fin du XX^e siècle; les conditions de leur introduction massive dans la production d'électricité sont d'ores et déjà réunies (existence de structures industrielles, connaissance des problèmes techniques); leurs avantages peuvent être rapidement rappelés: utilisant l'uranium 238, abondant dans la nature, ou l'uranium appauvri par les réactions nucléaires des centrales nucléaires classiques, ces réacteurs produisent une quantité de plutonium supérieure à celle qu'ils utilisent. Le combustible nucléaire devient alors un sous-produit de la production d'électricité, assurant ainsi la solution idéale au problème des ressources en matières fissiles.

Les réacteurs à haute température (*HTR*) constitueront un autre moyen de production d'électricité nucléaire; leur intérêt résulte d'ailleurs essentiellement de leurs possibilités d'utilisation dans *d'autres* domaines tels que la gazéification du charbon, la production d'acier, la chaleur industrielle et la production d'hydrogène.

Enfin il est vraisemblable qu'un certain nombre des tranches nucléaires en service à cette époque utiliseront la fusion thermonucleaire.

En ce qui concerne *la localisation* des centrales nucléaires, deux types de schémas peuvent être envisagés: on peut songer tout d'abord à réduire autant que possible leur nombre, en augmentant la taille des centrales: les sites futurs pourraient ainsi comporter 4 ou 6 tranches de 2500 MW. Cette solution permet de bénéficier des économies d'échelle, mais elle présente des inconvénients pour l'environnement: importance des rejets thermiques, création de microclimats, importance des ouvrages de transport de l'énergie produite. En sens inverse, la limitation de la dimension des équipements, "saupoudrés" sur l'ensemble du territoire, rentabilisés par l'effet de série, permettrait de résoudre les problèmes de site: la limitation des rejets thermiques permet d'utiliser des cours d'eau de débit moyen ou des réfrigérants atmosphériques de dimension réduite, ou encore des réfrigérants secs. En fait, la situation sera vraisemblablement caractérisée par une superposition de ces deux solutions: on sera conduit à rechercher la dimension optimale de centrales pour les sites disponibles, plutôt que de rechercher des sites correspondant à des centrales de dimension maximale.

En 2025, les équipements permettant de faire face à consommation annuelle d'électricité de 1800 TWh (produite à 90% à partir de l'énergie nucléaire) représenteront une puissance installée de 300 GW, répartie entre 40 à 70 centrales d'une puissance de 1 à 10 GW.

LES RESEAUX DE TRANSPORT ET DE DISTRIBUTION D'ELECTRICITE

L'énergie produite par les moyens de production définis ci-dessus sera débitée sur un réseau de transport à très haute tension (225, 380, 700 kV). Ce réseau atteindra, en 2025, près de 80 000 km, soit plus du double de la longueur du réseau actuel. La concentration des unités de production et la localisation d'une grande partie d'entre elles sur le littoral maritime conduiront à développer le réseau. Le choix aura été fait entre deux inconvénients: réduire la gêne qu'apportent les centrales en les rejetant loin des centres consommateurs ou réduire la gêne due a l'existence d'un réseau développé en rapprochant les centrales des centres de consommation.

L'effet nuisible sur l'environnement pourra être atténué par l'introduction de lignes à l'échelon de tension supérieur (700 kV) qui accroît la capacité de transport et par l'emploi de câbles souterrains (cryogéniques ou à isolation gazeuse).

L'utilisation de l'hydrogène comme moyen de transport de l'énergie pourra également limiter l'extension du réseau électrique.

La longueur des réseaux de distribution (à moyenne et basse tension) passera de 1 000 000 km en 1975 à 1 300 000 km en l'an 2000 et peut-être à 1 500 000 km en 2025.

La protection de l'environnement conduira à développer les techniques de dissimulation des ouvrages (pose en souterrain, galeries techniques).

LES AUTRES MODES DE PRODUCTION DE L'ELECTRICITE

Il convient, pour terminer, de préciser quel pourrait être l'apport en 2025 des autres sources d'énergies primaires: hydraulique (y compris le cas particulier des marémotrices) ou des énergies dites nouvelles.

1. Energie hydraulique

En supposant que tous les sites hydro-électriques du territoire national soient équipés, leur production annuelle ne représenterait que 80 TWh, soit moins de 5% de la consommation d'électricité de l'année 2025. En ce qui concerne l'énergie marémotrice, l'exploitation de toutes les possibilités marémotrices, conduirait à une production annuelle de 30 TWh, soit un peu plus de 1% de la consommation.

2. Energies nouvelles

Les énergies dites nouvelles: énergie solaire, énergie éolienne, énergie géothermique, constituent des sources d'énergie considérables, à l'échelle des besoins du siècle prochain. Malheureusement, elles ne paraissent pas susceptibles d'être utilisées pour la réalisation des moyens de production de *grande puissance* (c'est-à-dire de l'ordre des GW) qui seront nécessaires dans les prochaines décennies.

En effet, à titre d'exemple, indiquons quel serait l'équipement d'une centrale solaire ou d'une centrale éolienne équivalente à une tranche nucléaire de 1 GW.

La centrale solaire comporterait une surface de 6000 hectares couverte de capteurs ou de cellules photo-électriques.

La centrale éolienne comporterait 1000 aérogénérateurs, composé chacun d'une hélice de 30 m de diamètre, montée au sommet d'un support de 40 à 50 m de hauteur.

Toutefois des applications particulières localisées de l'énergie solaire (la maison solaire) et de l'énergie géothermique (utilisation des nappes d'eau chaude souterraines) sont susceptibles d'un développement intéressant et pourront apporter une contribution partielle à la couverture des besoins en énergie du premier quart de siècle du XXI^e siècle.

En résumé, le tableau de l'énergie électrique en France vers 2025 nous paraît pouvoir être caractérisé par les traits principaux suivants:

1) L'électricité fournit les 2/3 des besoins totaux en énergie, soit 600 Mtec sur 900 Mtec.
2) La production de la plus grande partie de cette énergie est assurée par un ensemble de 40 à 70 centrales nucléaires de puissance comprise entre 1 GW et 10 GW. Celles-ci sont réparties géographiquement sur le littoral et au bord des cours d'eau.
3) Le transport de l'énergie est assuré par un réseau électrique à très haute tension dont la longueur est de l'ordre du double de celle du réseau actuellement en service. Une partie du transport de l'énergie est assurée par un réseau souterrain de canalisations d'hydrogène.
4) La distribution de l'électricité est assurée au moyen de réseaux dont la longueur totale est de 50% environ supérieure à celle des réseaux actuels. Une partie importante des réseaux construits à partir des dernières décennies du XX^e siècle est dissimulée en vue de protéger l'environnement.
5) Le développement ainsi décrit est réalisé avec la préoccupation essentielle de préserver l'environnement, ce qui paraît techniquement possible mais entraîne un supplément de coût qui doit être supporté par la collectivité.

Bien entendu, nous devons être modestes et prudents et ne pas attacher à une telle description plus de valeur qu'elle n'en mérite.

Rappelons-nous, à cet égard, qu'un futurologue des années 1875 avait cherché à décrire les conditions de la circulation dans Paris en 1975: il avait calculé avec soin l'accroissement annuel du nombre de voitures à traction hippomobile en service, et le volume de déchets produits sur la surface des chaussées par les chevaux.

Il était arrivé à la conclusion que l'enlèvement de ces déchets risquait de conduire à une impossibilité de dépasser un certain trafic et qu'il convenait d'envisager des mesures autoritaires de réduction de la circulation.

Il avait tout simplement négligé d'envisager l'hypothèse selon laquelle, grâce à l'apparition d'un moyen nouveau que l'on a baptisé automobile, la circulation hippomobile dans Paris en 1975 serait réduite à zéro.

ANNEXE 1. Prévisions de consommation d'énergie totale et par tête en France

	1970		1985		2000		2025
1) Consommation totale							
Toutes énergies (Mtec)	225		400		640		900
Taux de croissance annuel (%)		+3,9		+3,2		+1,4	
Electricité (kWh)	140		420		1000		1800
(Mtec)	47		140		330		600
Taux de croissance annuel (%)		+7,6		+5,9		+2,3	
2) Population							
Millions d'habitant	50		58		65		75
Taux de croissance annuel (%)		+0,9		+0,8		+0,6	
3) Consommation par tête							
Toutes énergies (tec par tête)	4,5		6,8		9,9		12
Electricité (kWh par tête)	2800		7240		15 400		24 000
(tec par tête)	0,9		2,4		5,1		7,8

ANNEXE 2. Essai de bilan énergétique francais en 2025

			1970	1985	2000	2025
Consommation d'énergie primaire		Mtec	225	400	640	900
Consommation électrique		tWh	140	420	1000	1800
		Mtec	47	140	330	600
Production d'électricité						
	nucléaire	tWh	5,1	295	893	1650
		Mtec	1,7	98,3	298	550
	hydraulique	tWh	56,6	62	63	60
		Mtec	18,9	20,7	21	20
	thermique classique	tWh	79	65	50	90
		Mtec	26,3	21,7	17	30
Electricité primaire (hydraulique + nucléaire)		Mtec	20,6	119	319	570
Combustibles		Mtec	202,6	276	286	180
dont:	. pétrole	Mtec	131	191	206	140
	. CMS	Mtec	57	30	20	10
	. GN	Mtec	14,6	55	60	30
Nucléaire direct		Mtec	—	—	20	100
Energies nouvelles		Mtec	—	—	15	50
Part élecricité/énergie primaire		%	21	35,4	52,1	65
Part nucléaire/production électricité		%	3,6	70,2	89,3	90
Parc nucléaire électrique		GW	1,6	55	170	300
Parc nucléaire direct		GW équivalent	—	—	10	50

IS THE EMPHASIS ON ENERGY PRODUCTION THE OPTIMAL SOLUTION?

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Thank you, Mr. President. I want to congratulate the Institut de la Vie for its foresight a year ago in deciding to include energy as one of the key themes of this meeting. It must have been some act of prophecy on the part of the organizers to realize the importance of this subject. The year 2000 presumably was chosen as target date because it is the earliest time that matters decided now can possibly take effect. In fact this theme—the time constant—will be one of the main themes of my presentation. In analysing energy problems the standard format of presentation is to start with an analysis of possible energy demands for the future. We heard this morning such an analysis and we had an optimistic analysis by the first speaker, Mr. Destival, and I hope he is right. It is a difficult figure to arrive at and estimates vary greatly, as you have seen in the literature and heard this morning. The literature is very extensive and the numbers vary quite a bit, but all of them predict an appreciable increase in total energy demand. In particular, while the developed countries have reached or are approaching saturation—this was pointed out already today—the bulk of the world's population is still very far from such a situation. Therefore the bulk of the human race will increase energy demands at a much greater rate than those countries that are already at the peak but which represent only a small part of the world population. I am not going to go into the details of the demand here. Let us assume that the figures in the literature are reasonable and that we have some projection of what will happen in the year 2000. In any case there is very little we can do to change this situation because the time constant is almost out of control. We are not in the control of world population, we are not really in control of the way we use energy—it is a function of the way our society is formed. So, again, it is one of those things which cannot be changed very much between now and 2000. The next step in such an analysis is usually to go to energy resources. You have your demand estimate, then you want to check if the resources are reasonable. One is looking for limits or possible limits. Now here again I join the optimists—and I am an optimist myself—and I am prepared to accept the conclusion that there is no limit on resources. We foresee various developments in technology. But, again, nothing spectacular will happen before the year 2000 because of the time constant. So we can see that as far as resources go (that is: coal, oil, fusion reactors, breeders, fusion with deuterium or deuterium plus tritium), if we assume certain technological advances which I am prepared to accept, then there is no limitation. But having said that, we still don't know whether these resources will be available

at the price which humanity will be prepared to pay. By price I mean not only actual money but the cost to the environment, the cost to the quality of life, and the cost of social upheaval which large-scale production of energy may entail. I am avoiding this issue at the moment. I think these issues should be looked at very carefully because, as you know, many people suspect that the cost is too high to be acceptable. In fact, I consider the resistance to the introduction of nuclear energy today in some countries as a symptom, or as one of the first symptoms, of a refusal to pay the price which extra energy demands. We can foresee that if large-scale strip mining is introduced in various countries there may be a good deal of opposition to this solution. I think it is a major problem and that we should devote a lot of time to it. But for the purpose of my paper today I am prepared to assume that resources are available and that these problems of acceptability will be overcome. In the talk I am presenting today, as the title shows, I am seeking whether other limits exist. Are there, then, any other limits? The first limit that comes to mind is the environmental limit. The question posed in another way is whether we can dump so much energy, ultimately in a form of heat, into the environment without making the planet uninhabitable. Obviously at some point there is such a limit. We do not know today where this limit lies. It involves a detailed understanding of the way the atmosphere works, an understanding which is still lacking. It is a subject that is not easy to handle, and it is a relatively recent subject of interest to the world. Unfortunately, we are not in a position today to say that when humanity begins to emit so and so many watts of energy, then we may trigger some natural calamity. I am saying it this way because from the little that is known about the workings of the weather it is likely that the processes going on are not really stable; that one may have several stable states and one may flip from the one to the other by a relatively small trigger. Therefore the situation is dangerous and may not be reversible (or not easily reversible on a time scale that we are talking about, of hundreds of years). Therefore one has to be very, very careful not to accidentally overstep the limit. So that is one question mark. It is something we should worry about. Unfortunately, there is another limit which is much more immediate and which will prevent us probably from overstepping other limits, and that limit relates really to the kinetics of the process—the rate at which we can adapt the new technologies which the increase in energy supply will require. Many processes have been mentioned today as possible sources of energy, but if we translate them into more practical engineering terms—and that is an exercise that I recommend should be done in great detail—one very quickly gets the feeling that we are dealing here with a problem of staggering magnitude. If you deal with a situation that calls for the construction of one 1000 MW reactor per day for the next 25 years, and even when you have done that you still provide less than half of your energy from nuclear surplus, and you still need twice as much fossil fuel as you do today, then you realize you are facing a problem. You then ask yourself, What is the purpose of the exercise? Aren't we rushing around, making more and more energy at diminishing returns? Because, in order to arrive at the high rates of production of energy, we have to develop whole new infrastructures which do not exist today, whole new technologies, and new industries. These may be related to the nuclear field (isotope enrichment or construction of reactor vessels) or to steel production or to mining equipment, or to transportation—the list is very long. When one goes through this list—and this work has been done in a few countries—one really begins to realize that the task is almost impossible while at the same time doing other things. If the human race decided to devote itself to doing nothing but make energy, presumably it could do it. But it seems that we still want to live in some reasonable comfort and do other things but

produce energy. Then one comes to the conclusion that the limit is not the lack of primary raw materials for energy or even the limit of the effect on climate. The real limit—and here we are talking about 25–40 years—may be simply our ability to respond at the right rate to the changes which are demanded. I think that this is a point that has been missed in much of the thinking. The rate of response of technology is limited, and in fact the constraint will be our rate of response. If you accept the thesis that we can only respond at a certain rate and that this rate will really limit our development in energy, then you have to go back and, using the principles of systems analysis, ask yourself: Am I using my technological

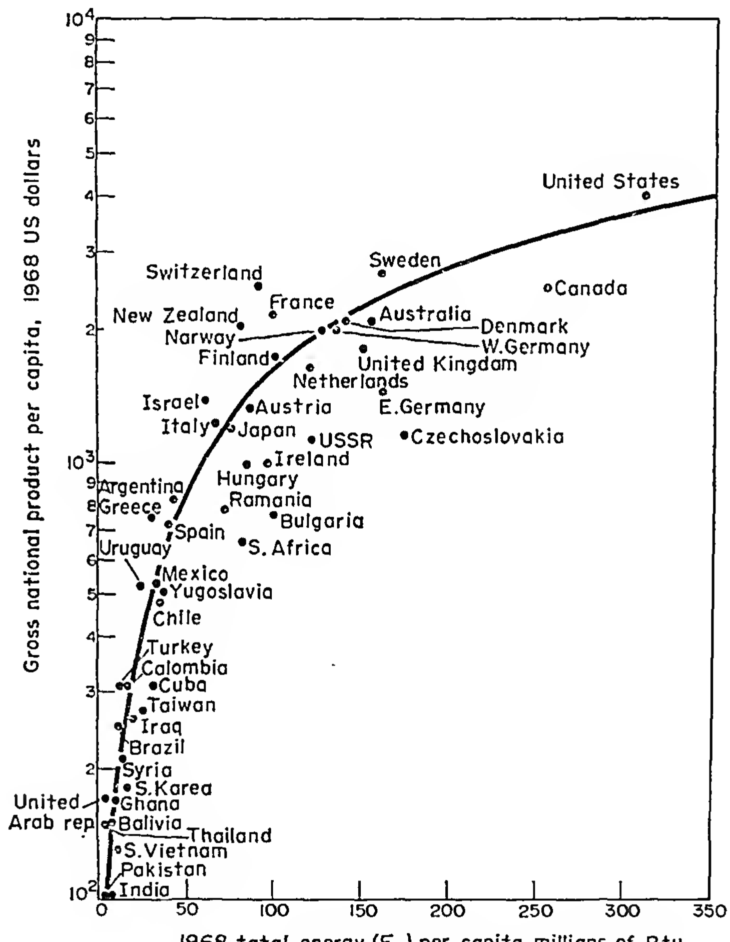

Fig. 1. Gross national product per capita vs. total energy E_T per capita consumption, 1968.

resources at my disposal in the best possible way? Is it really more effective for humanity to devote all its possible efforts to developing new energy sources or will it be more effective to split our efforts and to devote also some of it—and maybe a good part of it—to finding ways in which we can live well and improve our quality of life without the increase in energy consumption? It is commonplace to present figures or curves of GNP per capita versus energy consumption per capita—one of the previous speakers has done it—the figures or the curves are known. They usually show a situation where we have the United States way up in one corner and Asia in the other corner and the rest of the world smeared about in between (Fig. 1). There is a great mistake in using these curves as Holy Scriptures. In fact

I like to use these curves to demonstrate the opposite. If one looks at the curves in detail one sees several interesting things. Let us take as a first approximation that the GNP reflects in some sort of way a quality of life (this correlation has not yet really been proved). Everybody would agree, let us say, that the quality of life in Canada and the United States is better than in some more remote parts of the world. But even as one looks at this curve, one notes the following: that there are countries with a similar GNP, within a factor of 2, and yet with very differing energy consumption per capita. For example, I am not sure that people agree that the quality of life in France is inferior by a factor of 3 to the quality of life in the United States. The French would probably maintain that it is the other way around. But, anyway, one feels that France, the United States, and possibly Canada possess approximately the same quality of life. But the consumption of energy per capita in the United States is three times that in France; it is twice that in Britain. Nobody will say that the quality of life in Britain is so terrible. There are many, many other examples of that sort. In other words it is possible to achieve a high quality of life or a high GNP even without necessarily a high increase in energy consumption per capita. Since the variation is so considerable, and we are not talking here about a few per cent but about factors of 2 and 3, I think the message is quite clear. We should devote more effort in development in directions which increase the quality of life and increase the GNP without necessarily increasing energy consumption per capita. That message, I think, is particularly relevant to the developing countries. In other words, they should not follow the example of the United States but should try to follow the examples of other nations which have managed to reach a high quality of life without extravagant use of energy. Since the factors are so great, one can reduce the need, or ameliorate somewhat the excessive greed for energy, which most trend analyses indicate. However, that in itself is not enough. Unfortunately, we have to solve both problems simultaneously. Because of the time scale involved we still have to go on using up energy for the next tens of years at an increasing rate. At the same time we have to attack the problem of how to develop new technologies, new industries, new ways of life, new transportation, new urbanizations possibly, which are less energy demanding. What I am really suggesting is that one should really look at the two aspects of the system. Since there are limited human resources and our technological and scientific ability to respond to the needs is also limited, the question is, what is the optimal way of distributing these resources? Whether to put them all on more energy and forgo any efforts at developing systems which are less energy-intensive, or should we put all our efforts in the other direction and avoid the need to develop energy, or some mixture of the two? It is a typical case of analysis by a systems analysis method. I did not carry this analysis myself. It is a tremendous amount of work. I suggest that it could possibly be something that is worth devoting some international effort to. At the moment, incidentally, all that is happening in the world is talk. Now I do not see that any action has been taken towards a reduction of energy consumption, and time is proceeding. We are essentially in 1975, so that some kind of optimization of our effort is certainly indicated. If this conference results in some deep study of this optimization problem and comes out with some clear recommendation on this matter, I think we have achieved a great purpose.

DISCUSSION

LEARDINI: Thank you, Mr. Dostrovsky, for the very interesting point of view which is the other way around to the problem and for the hope that you expressed finally that more thought will be given to the optimation of the research among the two possibilities.

KELLOGG: I would like to raise a very small point in connection with the last talk concerning the question of ultimate limits to energy production. In a sense I will make a small commercial for the discussion, which I will present tomorrow morning, and a little preview. If we look at it in an optimistic vein, the question of climate change is probably not going to define an ultimate limit, especially if we handle energy production rightly. I will be talking about the climatic effects of what I believe might be an ultimate, very large rate of worldwide energy production. If you disagree with me after I've given my talk, well, that will be a subject for further discussion.

COULOMB: J'ai été assez surpris par la façon dont M. Gibrat et M. Destival ont mentionné la tendance à l'autarcie. Je suppose qu'ils y voient un fait plutôt qu'un souhait. Mais c'est une tendance à combattre. L'énergie est précisément l'un des domaines où il semble le plus nécessaire de penser internationalement. On peut évoquer les inégalités de répartition des combustibles et les risques dus à la toxicité du plutonium dont parlait M. Gibrat et qui déborderont certainement des frontières. L'autarcie a bien entendu des avantages temporaires mais fait perdre à coup sûr la partie à long terme.

GIBRAT: Je pense que nous avons d'abord à voir les faits: dans l'avenir, tel que je le vois, les surgénérateurs ne seront pas utilisés dans un but de moralité quelconque, ils seront utilisés parce qu'ils se présentent actuellement comme les plus favorables et par suite de leur propre structure ils entraînent, en ce qui concerne la production d'électricité, une véritable autarcie, qu'on le veuille ou qu'on ne le veuille pas. Nous n'aurons pratiquement plus besoin de ressources nouvelles. Les surgénérateurs consommeront les déchets obtenus dans la production d'électricité auparavant et ceci au moins pour de très nombreuses décennies. Si nous prenons l'énergie que j'ai appelée lointaine, ce n'est pas non plus dans un but philosophique ni politique. Nous trouvons que les trois énergies possibles sont toutes les trois parfaitement autarciques. Le soleil règne naturellement plus fort dans certaines régions que d'autres mais la différence n'est que de 1 à 2: en plein nuage on reçoit encore en énergie solaire la moitié de ce qu'on reçoit en plein soleil. La géothermie est pour tout le monde pratiquement avec simplement des gisements peut-être plus privilégiés. Et la fusion ne demandera pas non plus, autant que l'on sache, de ressources extérieures. Donc ce que j'ai voulu dire—M. Destival voudra peut-être ajouter sa propre pensée—c'est que la façon même dont nous prévoyons l'utilisation des sources va diminuer—est-ce un bien est-ce un mal, je ne sais pas—d'une façon considérable les problèmes actuels en ce qui concerne la production, c'est-à-dire l'utilisation des différentes ressources à l'échelle mondiale. Vous avez ensuite parlé du plutonium. Ça c'est un problème de sécurité, ce n'est pas un problème d'autarcie. C'est le même problème, celui que nous connaissons bien: un peuple n'a pas le droit de faire des rejets dans une rivière qui ensuite va se jeter dans un pays voisin. C'est un problème différent de l'autarcie.

DESTIVAL: Je suis entièrement d'accord avec ce que vient d'indiquer M. Gibrat. Je voudrais aller un peu plus loin: M. Ginocchio dans son exposé disait qu'il fallait s'attendre vers le début du XXI^{e} siècle à une plus grande spécialisation dans la production internationale. Je n'en suis pas persuadé. La spécialisation internationale a résulté pour une part de considérations géographiques naturelles qui perdront de leur importance—l'exemple de l'énergie en est l'exemple le plus frappant—Si des régions riches en énergie fossile comme la Ruhr, la Grande Bretagne, ont pu se développer très tôt grâce à cette ressource, il est certain que l'importance de ces facteurs va décroître. Il n'est peut-être pas souhaitable que certains types de pays, à terme de 50 ans, gardent encore la prédominance dans certains types d'activités et en rejettent d'autres vers d'autres pays. Je crois que les facteurs objectifs vont plutôt vers une déspécialisation internationale par rapport à la situation actuelle. Je voudrais, si vous me permettez de changer de sujet, faire une remarque à propos d'une indication du dernier conférencier: Aurons-nous à choisir sur quoi faire porter nos efforts, sur l'énergie ou sur autre chose? Dans les 30 dernières années, la part d'activité économique consacrée à la production et à la transformation de l'énergie n'a cessé de croître. Ainsi en France, il y a 20 ans c'était 20% de la formation brute de capital fixe qui était consacrée à l'énergie, aujourd'hui ce n'est même plus 10%. Les effets de la crise énergétique vont-ils obliger à augmenter l'effort à fournir? Dans la mesure où la croissance de la consommation d'énergie va diminuer, nombre d'investissements qui auraient été nécessaires pourront être différés, l'effort nucléaire ne compensant pas cette réduction. Il me semble que la part d'activité consacrée à l'énergie n'aura pas à augmenter.

LEWIS: You will be hearing from me as chairman this afternoon and in a paper tomorrow afternoon. I think it's rather important to speak at the moment to point out that I am not in agreement with most of the speakers and most of the thoughts that have been presented this morning. Nor do I think that I am unique. I am from Canada, and certainly our situation in Canada is very different—even from that in the United States. We consistently, since 1953, have been saying that we see no need in the whole world for breeder reactors. The breeder reactor, to take any place in the world, will have to compete with the alternatives. It so happens that people have been able to sweep the rival under the rug for a long time, but this is no longer possible. We have, in fact, operating in Canada the largest nuclear power station known in the world in 1973, and in that year it produced 40% more power than its close rivals at a cost that was less than that of some of the hydropower in Canada. So this forms a background. But I am basing my point more on history. Why did we know in 1953 that this would be so? I can go back to 1946 when Cockcroft handed over to me at Chalk River a little document that said that if the world wants nuclear energy abundantly there are two routes open: one is with thermal reactors and thorium, and the other is with fast reactors and plutonium. That is still true today. What we are seeing is that the thermal reactors with thorium are establishing an extremely low cost, that it will be very difficult for any fast breeder to meet in economic competition. You have your fast breeder, to quote a note passed me this morning . . . if this Freudian religion of breeding is something that gets you! But you needn't . . . you might be a cold-blooded economic engineer and say it is unnecessary because we have something cheaper. I remind you that if one wants to be disparaging about the breeder, it can't burn anything more than the uranium you put into it. You're only just cheating by separating uranium into a fissure component and fertile component. We're doing the same thing on thorium. It is a fertile component going through a fissile component to produce the energy. But it isn't breeding. So this—I just want to make clear that this attitude makes a very different situation because we see that—as I shall say tomorrow I hope with some conclusive evidence—that the day of low-cost energy for people lies ahead. Dr. Dostrovsky was saying that this depends on our human resources, our human effort. If we put this effort in, in a reasonable manner, this energy will be there at a lower cost than tomorrow.

LEARDINI: Thank you, Dr. Lewis, for your kind remarks and for putting upside down the commonly accepted philosophy of economy of the breeder reactor.

LEWIS: The geochemists have set the figure for the abundance of thorium in the earth's crust at three or four times the abundance of uranium. However, the chemistry of thorium and of uranium differ, so that the distribution of thorium is not the same as the distribution of uranium, although it happens that in certain regions that are counted as major resources of uranium they are also major resources of thorium. The Elliot Lake deposits in Canada, for example, must average something like three times as much thorium as uranium, although the ratio varies quite a bit. India has in the monazite sands a very high ratio of thorium, but one can go on talking about uranium for a long time. Not all thorium is equal, because there is an isotope in the uranium decay chain called ionium or thorium-230, an isotope of thorium, therefore separating thorium from a uranium-rich ore gives you a different isotopic content.

DATTA: I agree with Dr. Lewis partly in what he said, that the circumstances in different countries will vary. But definitely in the context of the conditions of the developing countries you have to see the needs, perhaps much more closely and seriously than the technology. As in an industrialized country, sophisticated technology-oriented plans will not exactly fit in a developing country. The needs of the developing countries certainly are different in the sense that outlook towards life is different and basic material needs are comparatively less, and energy consumption is consequently less. We had occasion to examine in our country (India) and analyze the situation of the energy in the context of our country's needs, and we have found out in the process of this analysis and extending the observations to other developing countries that the requirements are generally for medium and small scale uses of energy, whereas for the developed countries, in general (I shouldn't say that this is 100%), the tendency is that there is a fairly large scale use of energy. In implementing the result of this analysis in our country we found that we have also some resources to overcome the energy crisis which has affected our own and also other developing countries very seriously and certainly also has affected the developed countries severely. Further, oil cannot be a very dependable and assured source of energy for us excepting perhaps in the course of time, and in future we shall have to confine ourselves to the use of some meager source of oil for recovery of chemicals. We have got plenty of coal in our country, perhaps for another 300 years or more, so we do not have to bother much. As a matter of fact, for some of the larger and smaller industries, coal is becoming the mainstay as the source of energy. I would like to put emphasis on this thing that in the planning of energy sources or energy requirements, all the world over, the needs of the developing countries have got to be taken into account in counting the requirements of the energy, mainly emphasizing the basic needs of life. I must mention that such basic needs around which we have to base our energy planning in the country are: food, housing, clothing, medical aid, and education. But in a developed country these needs are cared for, but not to the extent the developing countries have to. Therefore I suggest that in the planning of energy for future mankind the needs of the developing countries and the realities therein should have to be taken into account.

LEWIS: Answering the last contributor, I believe I have some understanding of the conditions in India. I have written two joint papers with the late Homi Bhabha on this subject. This is not just discussing nuclear

energy, but also discussing coal. It comes back to what I think Dr. Dostrovsky was saying: it is this human effort, the savings from that effort in its operation, which are necessary first. One of the constraints on the coal development is the question of the means of transportation—whether there is a railway and rolling stock. All these things have to be found, so that the rate of build-up of the use of coal is limited, just as is the rate of build-up of the use of nuclear power or any harnessed power. The mix may not be determined entirely by economics—I think you'll agree—but somewhat by local preferences. I understand the situation is that, certainly near Madras in the same area, there is both coal development and nuclear going on.

DATTA: I make, Mr. Chairman, a very clear-cut distinction between (a) rural areas, (b) urban areas, and (c) metropolitan areas in our country. I invite members to see the conditions therein and make recommendations specially for rural areas where nearly 80% of our people live. Many of these areas are highly dispersed; the transportation problem is severe; even transportation of coal is almost impossible in these areas. So under these conditions we do not think in terms of coal for these rural areas. It is pertinent to mention that the energy requirements for the above-mentioned areas differ widely. We have recently done some research. In rural areas there are villages which hardly need 250 kWh per day per village. If we see the urban areas, the requirement of energy goes up to, say, 1000-10,000 kWh per day. In metropolitan areas this requirement is very much higher. So the situation of coal and the getting of energy from the use of coal can be improved only in the metropolitan areas by providing better transport. But for the rural areas we cannot think in a big way in terms of coal or oil as source of energy on account of questionable transport which is very, very difficult.

BLACKSHEAR: I wish to comment on aspects of this discussion dealing with the quality of life. One measure of the quality of life frequently used is freedom of choice. The lesson I hope many of us learned following the recent increase in petroleum prices is how expensive are the consequences of not having the freedom to choose between alternative sources of energy. We are over-dependent upon petroleum and specific sources of petroleum. As a result of this lesson I am reluctant to be over-dependent upon nuclear energy.

One could argue that, to insure choice, a balanced research and development program supplying a diversity of energy sources (coal, fission, fusion, solar electric, solar thermal, biomass, geothermal, wind, etc.) would be required. Further, it would seem prudent to have independent laboratories with independent funding develop these sources and generate real competition in energy availability. I argue, therefore, that the quality of life considerations support an independent diversified research effort on all possible energy sources.

HUET: Mr. Destival nous a indiqué qu'il y a dans l'évolution récente des facteurs qui contribuent à modérer le rythme de l'accroissement de la consommation d'énergie. Je voudrais lui demander s'il estime que, dans ces conditions, nous pouvons considérer que les éléments régulateurs naturels suffiront à aboutir dans un délai de 25 ou 50 ans à une consommation d'énergie supportable; car s'il nous a dit qu'il n'y avait pas de problèmes sérieux d'approvisionnements, nous avons eu dans deux des exposés du matin des indications qui conduisent tout de même à nuancer cette appréciation. Mr. Ben Mena nous a indiqué, et je crois qu'il a raison, qu'un effort doit être fait pour économiser les ressources actuelles d'hydrocarbures et ceci d'autant plus qu'il constituent une matière première précieuse pour d'autres usages, pour la chimie en particulier; et Mr. Dostrovsky a insisté sur le fait qu'il y des facteurs de limitation autres que les ressources disponibles, qui sont la capacité industrielle et humaine en général et le niveau des prix. Dans ces conditions, ma question est la suivante: est-ce que notre conclusion sur ce point sera que tout est pour le mieux dans les mécanismes normaux de l'économie et en particulier que la hausse des prix et autres facteurs économiques suffisent à réduire le rythme de croissance des besoins de l'énergie ou est-ce qu'au contraire, comme je le pense, une action des pouvoirs publics est nécessaire à cet égard et comment peut-on l'envisager?

DESTIVAL: La première question de M. Huet est: avec un certain ralentissement de la demande arrivera-t-on à un niveau de consommation raisonnable? Mais par rapport à quels critères? Si nous admettons qu'il y a de l'énergie en suffisance pour tous il n'y a pas là motif à l'économiser. Ce n'est donc pas un critère par rapport auquel on peut dire qu'un niveau est trop élevé. Il y a les incidences sur l'environnement. Je pense qu'on peut les contrôler mais ça sera un sujet de débat ultérieur. Elles pour raient effectivement constituer une contrainte quantitative. Je ne le pense pas. Elle n'existe pas au niveau de la planète, certains l'ont déjà dit. Si elle existe localement, il faudra en tenir compte, dans l'organisation des infrastructures énergétiques. Ceci n'est pas impossible, il suffit d'anticiper suffisamment dans les effets pour savoir quelle décision nous devons prendre. Donc je pense qu'il n'y a pas là de motif suffisant pour économiser de l'énergie, pour l'énergie elle-même. Par contre est du devoir de tout agent économique et notamment de tout gouvernement de faire en sorte que l'énergie soit utilisée rationnellement en fonction de son coût. A cet égard, compte tenu du choc, que nous venons de subir, il est bien certain que nous sommes à des niveaux de consommation qui sont économiquement injustifiés, beaucoup trop élevés, et que l'agent économique, l'homme en général, a une inertie telle qu'un nouvel équilibre ne sera retrouvé qu'avec de longs délais—délais que les gouvernements par leurs actions volontaires peuvent réduire. C'est là le rôle d'un gouvernement que d'inciter les agents économiques à remettre en cause leur propre procédé d'utilisation de l'énergie pour minimiser le total

des facteurs mis en œuvre de production. C'est un rôle essentiel pour lutter contre le gaspillage—non pas physique (de telle matière) mais économique.

N'oublions pas que la quasi totalité de l'énergie que nous consommons est restituée à l'atmosphère sous forme de chaleur. Le chauffage d'un logement ne sert qu'à alimenter des pertes thermiques; le gaspillage y serait—il de 100%?

Je reviens sur les deux autres contraintes que vous citiez: capacité industrielle, niveau de prix.

Capacité industrielle: je crois que pour faire face à la croissance des besoins d'énergie, l'économie mondiale ne consacrera pas une part plus importante d'investissement à l'énergie; dans le passé cette part a constamment diminué. On dit le nucléaire très capitalistique: une centrale nucléaire en investissement n'est pas plus chère—si l'on considère tout ce qui est en amont: la mine d'uranium et l'usine d'enrichissement—qu'une centrale au fuel si l'on inclut aussi la raffinerie, le bateau de transport, l'exploitation et la mise en production du gisement. Toutes les énergies sont très capitalistiques. Dernier facteur: le renchérissement des prix. Je crois qu'il faut préciser les ordres de grandeur. L'énergie primaire, c'est-à-dire la ressource initiale, celle sur laquelle le changement de prix a porté. Qu'est-ce que c'est dans l'activité économique d'un pays? C'est 2% à peu près du PNB. On dit que l'augmentation du prix du pétrole porté un coup aux économies industrielles. Cela tient à la brutalité du phénomène. Si au lieu d'une marche d'escalier on avait eu une évolution régulière depuis 1960 des prix nous ayant conduit au niveau actuel personne n'aurait sans doute parlé de l'impact du prix de l'énergie sur l'activité économique. Quel est le résultat actuellement de l'augmentation du prix du pétrole? C'est un prélèvement pour un pays comme la France de 3% sur notre activité économique, sur notre consommation intérieure, moins que l'augmentation moyenne annuelle de notre consommation intérieure. Le problème est celui de la transition, du réequilibrage des échanges extérieurs, du déséquilibre de l'ordre monétaire, mais en soi le phénomène n'est pas majeur dans une vue à très long terme. Le niveau de prix actuel n'est sans doute pas insupportable. Ce qui est pénible c'est la réadaptation à cette nouvelle situation économique. L'économie s'accommode mal des marches d'escalier. Observons enfin que cette augmentation du prix du pétrole ne représente pas une augmentation des facteurs de production nécessaires à l'économie mondiale. Il représente un transfert de pouvoir d'achat entre populations. C'est pourquoi je reste optimiste sur le long terme.

Chapter II

POTENTIAL RESOURCES IN THE YEAR 2000 FROM NEW TECHNIQUES AND THE PROBLEM OF TRANSPORTATION

Président: W. B. LEWIS

CONTENTS

ENERGY OPTIONS DURING THE NEXT TWENTY-FIVE YEARS

CONVENTIONAL FUELS, NUCLEAR POWER, AND RENEWABLE ENERGY SOURCES

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Abstract. This document presents a series of charts and related discussion concerning global reserves and utilization of fossil fuels, nuclear fuels, and geothermal and solar renewable energy sources. Two energy scenarios are presented, demands are projected to the next century, and potential phasing of fossil, nuclear, and solar energy sources to satisfy these demands are described and examined for feasibility.

Based upon predicted rates of consumption, our current global reserves of petroleum and natural gas will be depleted in about 50 years, uranium in 235 years, and oil shale in 100 years. Only coal, which constitutes over 80% of the world's fossil fuels, will last for 400–500

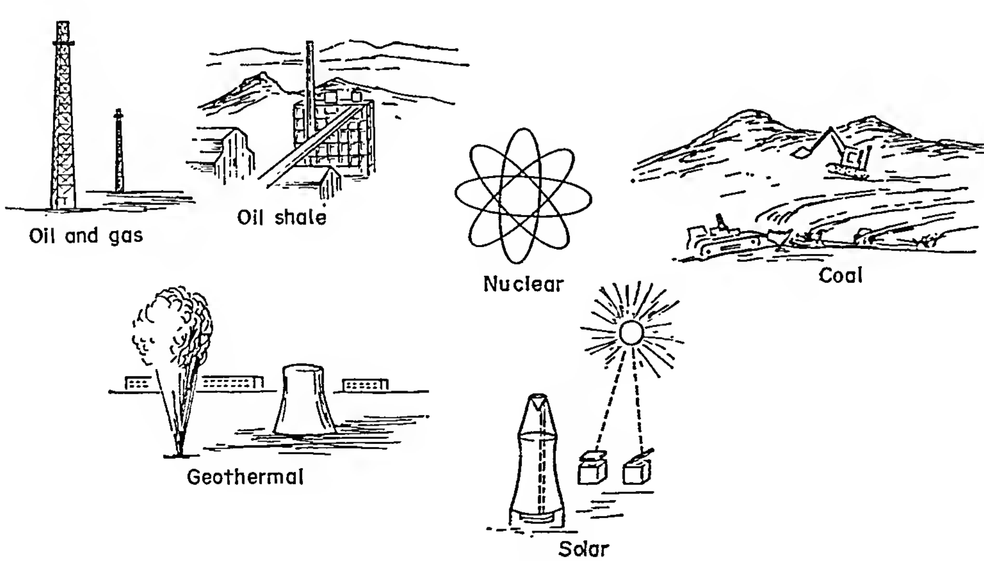

Fig. 1. Energy options during the next 25 years.

years. We must consider means of utilizing our fossil fuels in an efficient and environmentally acceptable manner. Similarly, we must consider options such as nuclear energy and renewable solar and geothermal sources to reduce our reliance on diminishing fossil fuel supplies. Decisions which will be made in the next few years and implemented over the next 25 years will determine the nature of man's energy economy for centuries to come.

This chapter presents an overview of energy options (Fig. 1), some of which may be implemented during the remaining quarter of the twentieth century.

The section of fossil fuels highlights the status of resources and reserves and depicts production and consumption on a global basis. Potential development of oil shale and conversion of coal to more environmentally acceptable fuels are briefly described.

The nuclear options for generation of electricity are identified and availability of nuclear fuel is presented as a function of price. Projected deployment of nuclear generating capacity is also considered.

Selected aspects of renewable energy resources in terms of solar and geothermal options are also discussed.

Finally, alternative scenarios, depicting how we may shift from relying on fossil fuels to increasing our utilization of the other sources, are discussed in the concluding section.

FOSSIL FUELS

Fossil fuels (Fig. 2) account for about 92% of our total energy use; the balance is made up primarily of nuclear energy and hydro-power for generating electricity. Nuclear energy will be used for electricity generation which currently accounts for 26% of the total US energy consumption. Significant impacts from renewable sources are unlikely to occur before 1985–90. Hence, fossil fuels will continue to supply most of the energy needs over the next 25 years.

Major questions relate to the rate at which petroleum exporting nations, chiefly in the

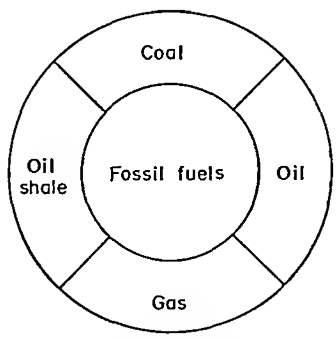

Fig. 2. Fossil fuels.

Middle East, will be willing to deplete their reserves and the prices they will charge for supplying the growing demand of industrialized nations. Related to this issue is the ability of the United States to convert plentiful but dirty coal to environmentally desirable oil and gas as a substitute for crude oil and natural gas. A significant capability in this area, along with production of oil from shale, would reduce our dependence on foreign sources of hydrocarbons during the latter portion of this century. Still another alternative is to in-

tensify exploration and development of new potential sources such as the Outer Continental Shelf.

All the options—reliance on foreign sources, conversion of coal, development of an oil shale industry, and additional exploration—are costly and have their associated risks. This section highlights the world's fossil fuel situation.

COAL RESERVES OF THE WORLD

North America has over a third of the world's coal reserves (Fig. 3). The US reserves are estimated at 193 billion tons. About 35% of these are located west of the Mississippi River. In 1973, about 590 million tons of coal were produced in the United States. There are sufficient reserves to last for several centuries based on current usage.

If there were no restrictions on supply, coal would provide only 22% of the world's

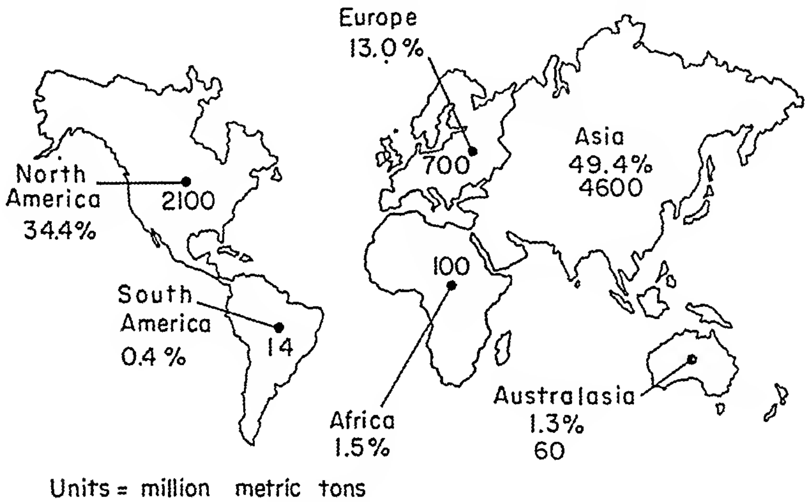

Fig. 3. Coal reserves of the world.

energy over the next 30 years. Oil and gas, which only constitute about 7% of the reserves, would provide 67% of the world energy needs over the same period.

The Department of Interior is targeting for a threefold increase in domestic coal production by 1985. In 1970 the average sulfur content of all coal burned in the United States was 2.6% by weight. Under the State Implementation Plan regulations, the allowable emissions would be equivalent to an average of 1.4% by weight.

With a deferral in emission regulations and with significant requirements for coal conversion by 1985, this source may carry a substantial share of meeting the nation's energy needs over the next 25 years.

Figure 4 describes the basic steps in coal gasification and depicts some of the effluents produced during the conversion process.

COAL-GASIFICATION-RELATED EFFLUENTS (Fig. 4)

Coal preparation includes grinding and pretreatment to minimize caking. Prior to gasification, the coal is devolatized to a material that is primarily fixed carbon and ash.

Toxic organic compounds are released, along with trace metals including mercury, cadmium, and lead. The process occurs at temperatures and pressures ranging from 130°C and 1 atmosphere to 700°C and 400 psig.

Gasification involves treating the carbon char with oxygen (or air) and steam at temperatures ranging from 800–1100°C and at pressures ranging from 150 psig to 1500 psig. The gaseous product contains carbon monoxide, carbon dioxide, hydrogen, and methane. Appreciable amounts of toxic effluents are also produced. The gas is passed through a scrubber to remove tar, dust, sulfur compounds, phenols, and ammonia.

Shift conversion involves adjusting the CO to H_2 molar ratio to 1 : 3. Reduced sulfur compounds, ammonia, and benzene are removed during the purification stage. Removal

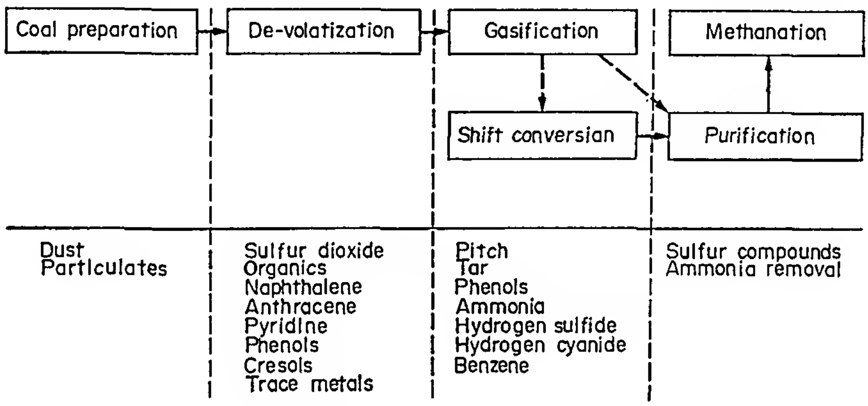

Fig. 4. Coal—gasification—related effluents.

of sulfur compounds is essential to the process since they poison the nickel catalysts used during the next methanation step, where hydrogen and carbon monoxide are reformed to produce methane for pipeline transmission and subsequent utilization.

In addition to producing pollutants associated with coal combustion, conversion processes introduce other hazardous pollutants for which effects and control measures are little understood.

The COED process, which would utilize 28 400 tons of coal per day to produce 250 million cubic feet of pipeline and gas and 29 000 barrels of syncrude daily, would require a $500 million capital investment. Product cost would be about $1.50 per million BTU. Water requirements for operations of this scale could range from 10 000 to 40 000 acre-feet/year.

COST COMPARISONS OF ENERGY TRANSMISSION ALTERNATIVES (Fig. 5)

Transmission of electrical power by extra-high-voltage AC lines is unstable over long distances. High voltage (500 kV) DC systems are economical over long distances, but AC–DC conversion costs are high.

Unit trains are an economical means of transporting coal, but for distances in excess of 500 miles overland transportation costs increase linearly with distance. Railroad and barge systems may not be sufficient for hauling large quantities of western US coals to eastern markets.

Coal slurry pipelines can supplement coal transportation needs and are economically attractive for amounts in excess of 5–6 million tons per year. A 280 mile line in the southwestern United States is capable of moving 5 million tons per year. A 25 million ton per year line about 1000 miles in length is currently being designed.

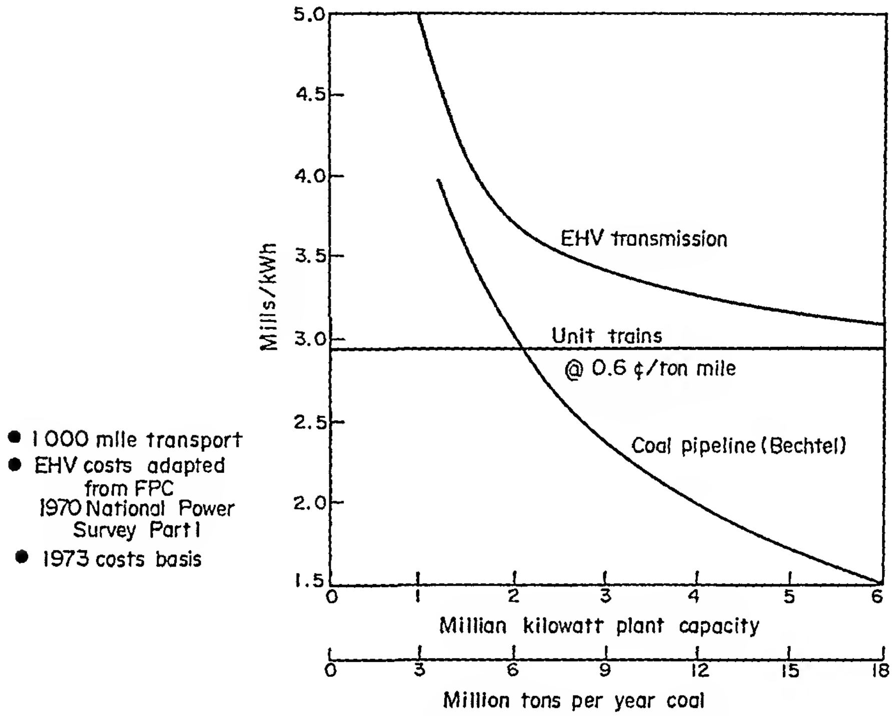

Fig. 5. Cost comparisons—energy transmission alternatives.

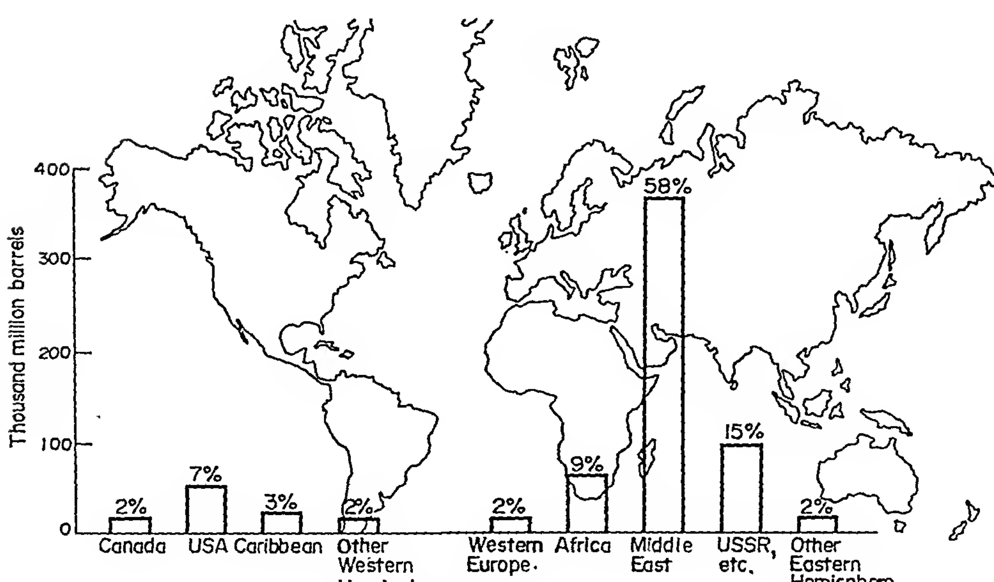

Fig. 6. World oil reserves, 1971.

WORLD OIL RESERVES

As of the end of 1971 there was a worldwide total of 642×10^9 barrels of oil in the ground which geological and engineering information indicate with reasonable certainty to be recoverable in the future under economic and operating conditions of 1971.* The data exclude the oil content of shales and tar sands. The percentages shown on the graph (Fig. 6) have been rounded to the nearest per cent. Some 14% of the oil is in the Western Hemisphere (i.e., the Americas). These reserves represent about a 36 year supply based on the 1971 consumption rate.

WORLD OIL PRODUCTION AND CONSUMPTION, 1971

In 1971 the oil production (in 10^9 barrels per year) for various geographical areas in the world (Fig. 7) was as follows:*

Geographical areas	Production	Consumption
United States	3.56	5.40
Other Western Hemisphere	2.48	1.68
Western Europe	0.16	4.81
Africa	2.12	0.34
Middle East	5.90	0.40
USSR, etc.[a]	3.03	2.68
Other Eastern Hemisphere	0.56	2.50
Total	17.81	17.81

[a] The USSR, etc., category includes all of the so-called centrally planned economies.

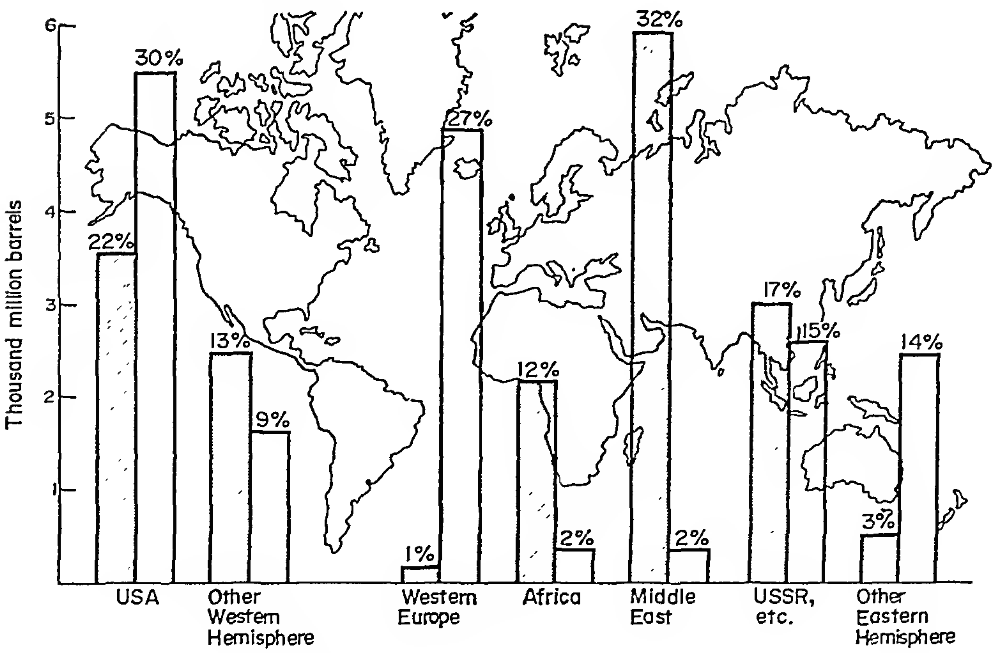

Fig. 7. World oil production and consumption, 1971.

* *British Petroleum Report*, 1971.

WORLD NATURAL GAS RESERVES

As of the end of 1971 the worldwide natural gas reserves (Fig. 8) amounted to some 325×10^9 equivalent barrels of oil.* For the United States the value includes about 10% of "gas liquids". The percentages are rounded to the nearest per cent. These reserves represent a 38 year supply based on the 1971 consumption rate.

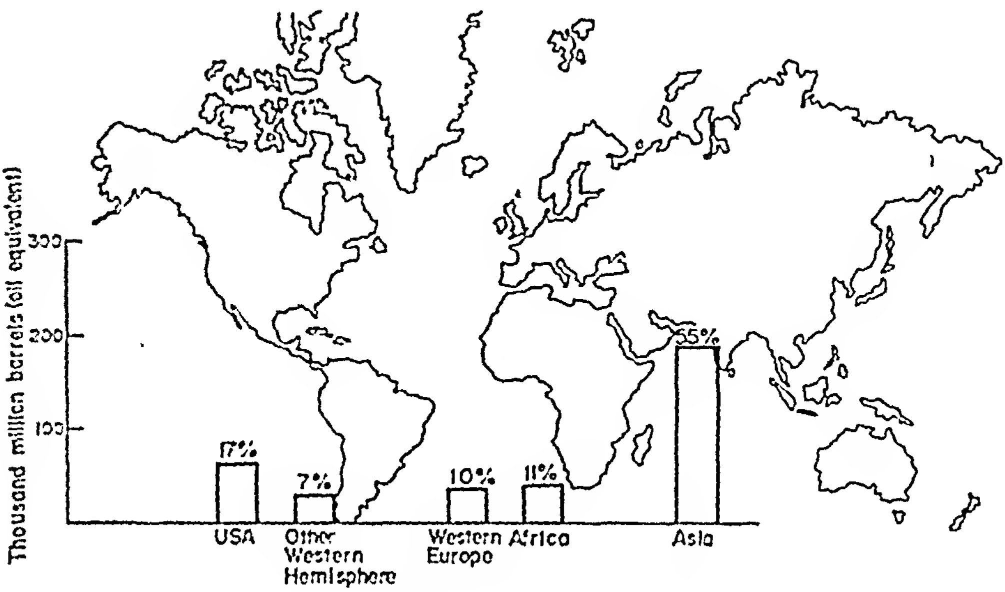

Fig. 8. World natural gas reserves, 1971.

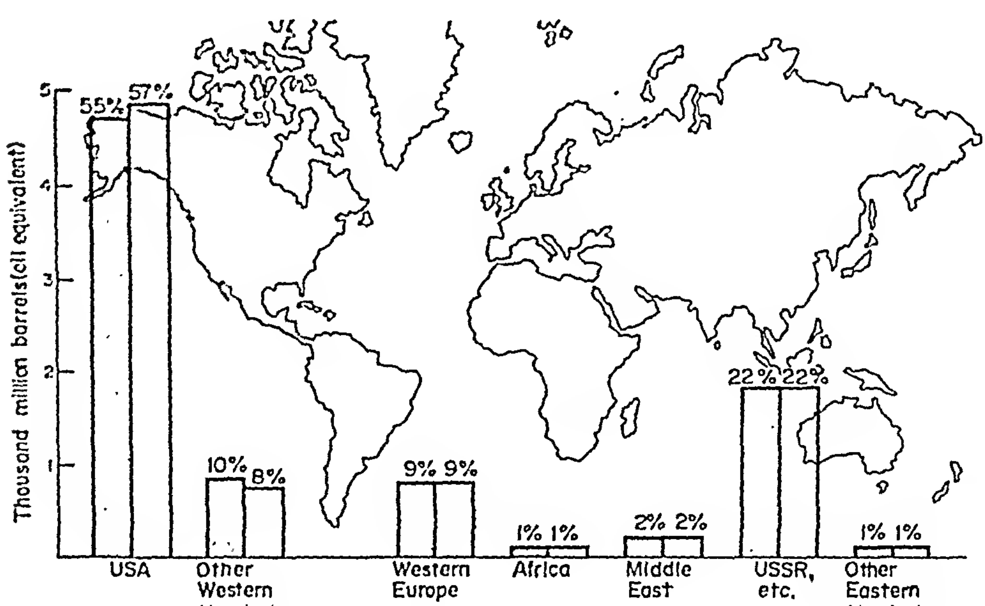

Fig. 9. World gas production and consumption, 1971.

* *Energy Facts*, Congressional Report, November 1973.

WORLD GAS PRODUCTION AND CONSUMPTION, 1971

In 1971 the natural gas production (Fig. 9) (in equivalent 10^9 barrels of oil per year) for various geographical areas in the world was as follows:*

Geographical areas	Production	Consumption
United States	4.35	4.83
Other Western Henisphere	0.85	0.69
Western Europe	0.78	0.79
Africa	0.03	0.01
Middle East	0.18	0.18
USSR, etc.	1.87	1.89
Other Eastern Hemisphere	0.11	0.08
Total	8.47	8.47

TRANSPORTATION COSTS VERSUS TANKER SIZE

In 1973, costs per ton of cargo ranged from $8.00 for 50 000 dwt to $4.25 for 500 000 dwt. Comparable costs for 1975 range from $9.34 to $5.16 (Fig. 10). Future transport costs are critically dependent on harbor facilities which are capable of handling the largest type of tanker size compatible with the demands of the country.

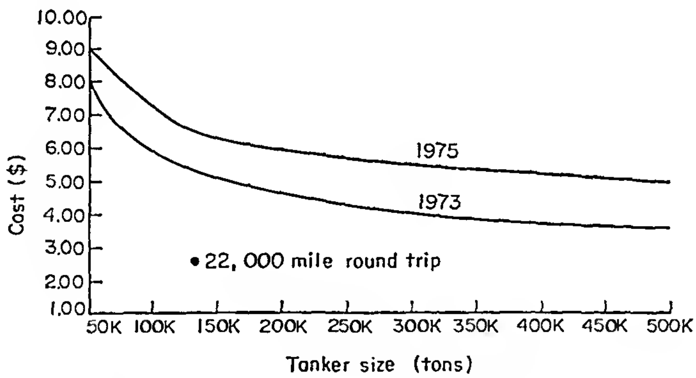

Fig. 10. Transportation costs versus tanker size.

More than 80% of total tanker tonnage on order today is for vessels in excess of 200 000 dwt. Over 60 deep water ports exist throughout the world which are capable of handling supertankers with drafts in excess of 65 feet. The United States today is without a deep water port; US ports are served by tankers whose average size is slightly less than 50 000 dwt.

INLAND PIPELINE COSTS

Figure 11 refers to pipeline sizes most likely to be encountered in oil-importing developing countries. The cost per ton of oil is sensitive to very large throughputs. For example, for a

* Information derived from *World Energy Supplies, 1968–71,* United Nations Report ST/STAT/SER. J/16, 1973.

	Throughput	
	2×10^6 t/yr (10-in diam. pipeline)	5×10^6 t/yr (16-in diam. pipeline)
Costs (US cents/t per 100 miles)		
Capital	60	39
Other fixed	18	10
Variable	4	8
Total	82	57
Total cost (US cents/10^6 kcal per 100 miles)	8.1	5.6

Fig. 11. Inland pipeline costs.

pipeline with a transport capacity of 50 million tons per year the costs would drop to 20 cents per ton per 100 miles or to about one-third of the 5 million ton per year figure.

Capital costs are based on \$9000 per inch diameter per 100 miles with flat terrain and no major river crossing.

The 2 million ton per year is sufficient for supplying 1200 MW oil-fired plants at 80% load factor.

The 5 million ton per year could supply a 3000 MW oil-fired plant at 80% load factor.

WORLD SHALE RESERVES

As of the end of 1971 the estimated worldwide reserves of shale oil amounted to some 190×10^9 barrels of oil.* It has been assumed that there is a one-for-one energy content equivalence between a barrel of crude oil and a barrel of shale oil.

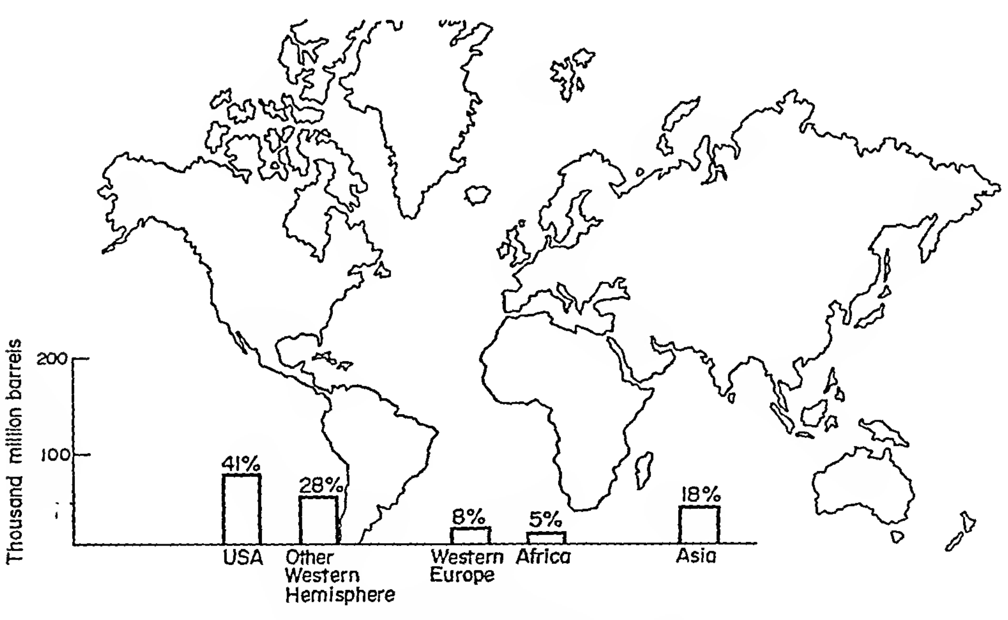

Fig. 12. World shale oil reserves, 1971.

* *Energy Facts*, Congressional Report, November 1973.

US OIL SHALE DEPOSITS

Estimates of reserves in the 16 000 square mile Green River Formation are (Fig. 13):

2×10^{12} barrels

130×10^{9} barrels at 35 gallons per ton; 30 ft thick strata within 1500 ft below ground.
These are distributed as follows:

Piceance Creek Basin (Colorado)—80%
Uinta Basin (Utah)—15%
Green River, Washakie, and Sand Wash basins (Wyoming)—5%

Private lands—22%; Federal land—78%

Of the 130×10^{9} barrels, room and pillar mining will leave 40–50% "in-place" reserves, for an estimated $65\text{–}78 \times 10^{9}$ barrels potentially recoverable.

Private operations include Colony Development Corporation and Union Oil of California along Parachute Creek in Colorado. The Department of Interior has leased four

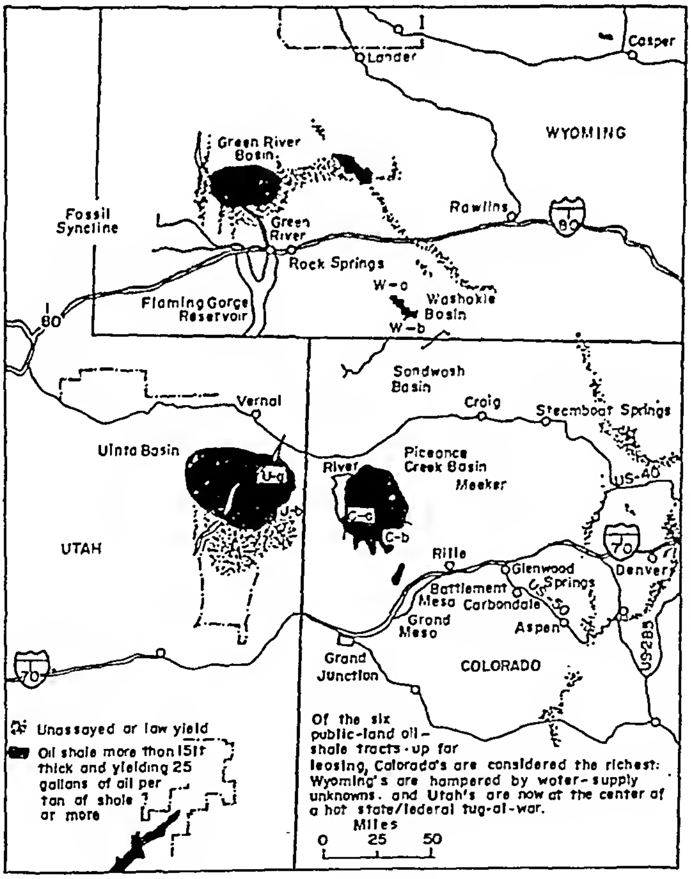

Fig. 13. US oil shale deposits.

tracts, two in Colorado and two in Utah. Production estimates by 1980 range from 100 000 to 300 000 barrels per day.

A ton of shale mined and stored will yield at most 17.5% by weight of useful organic

material. Hence, a one million barrel per day industry will require mining 480 million tons of shale annually and disposing of spent shale. This mining operation obtains about 19% of the BTU content of extracting an equivalent amount of coal. It would require about 175 000 acre-feet of water, about half of what the Bureau of Reclamation estimates is available for present use in the upper Colorado Basin. Annual output of salt loading from spent shale leachate is estimated at 5.2 million tons. Water quantity and quality could be a significant constraint in developing this industry.

Land reclamation is also a significant problem. A 500 000 barrel per day industry would require filling, stabilizing, and restoring 5 square miles of tailings 40 ft deep, each year.

OIL SHALE PROCESSING (Fig. 14)

Colony Development Corporation will extract 60% of the shale by room and pillar techniques. Front end loaders will place the broken shale rocks in trucks for movement to the primary crusher. Coarse ore is stockpiled and moved to final crushing and sizing and conveyed to the retorting plant. Colony will mine about 61 000 tons per day, eventually mining 4100 acres.

Conversion encompasses two sequential steps: retorting and upgrading. All retorting

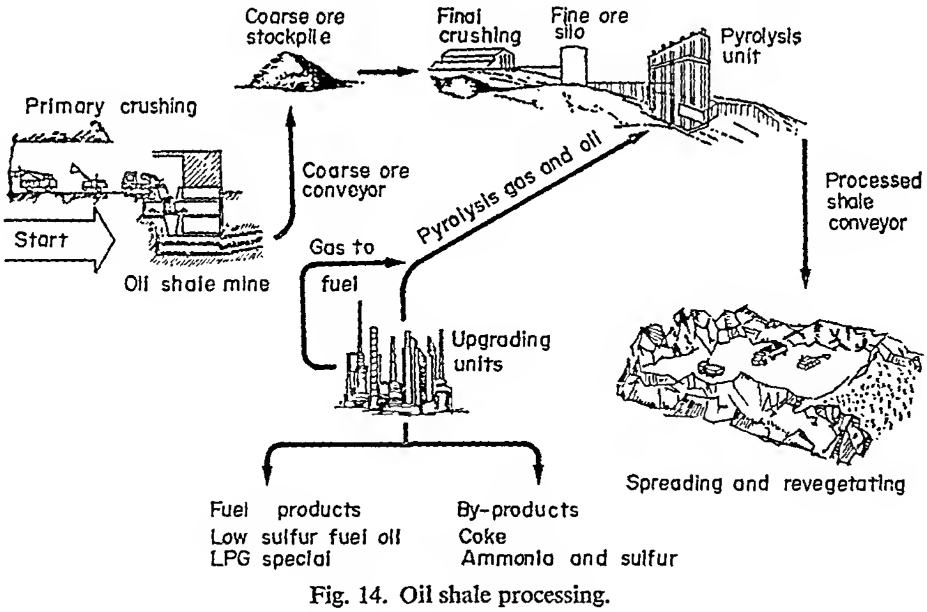

Fig. 14. Oil shale processing.

methods are based on heating crushed shale to 900°C or higher. Such pyrolysis results in decomposition of organic matter to yield oily vapors which condense to a viscous liquid shale oil. Methods include:

(1) recycled hot solids (Tosco II; operational at 1000–1200 tons per day; ready for commercial scale-up);
(2) internal combustion zone within retort (Union Rock Pump—Type A; status same as Tosco II);
(3) external fuel-fired furnace (Petrosix Process; operational in Brazil at 2500 tons per day).

In situ processing involves fracturing the shale and in-place pyrolysis. Proponents of the Occidental Process claims it will be cheaper, applicable to lower grade deposits, and less polluting than "traditional" methods. Operation is unlikely before 1985.

Upgrading is needed to produce a refinery feedstock and a less viscous fluid for pipeline transport. Hydrogenation converts hydrogen to ammonia and sulfur compounds to hydrogen sulfide which is converted to elemental sulfur. Oil products and useful fractions will be piped out of the area.

GEOTHERMAL HEAT FOR ELECTRIC POWER GENERATION

Geothermal energy is in the form of heat which is obtained from the earth's magmatic heat. Heat energy can be converted to electricity by passing hot pressurized water available within the earth's crust through a turbine connected to an electric generator. Alternately, a heat exchanger can be used with a working fluid characterized by a low boiling point with comparatively high pressure.

The upper portion of Fig. 15 shows a typical *convective hydrothermal* system where surface water seeps through porous channels to a point where it comes in contact with

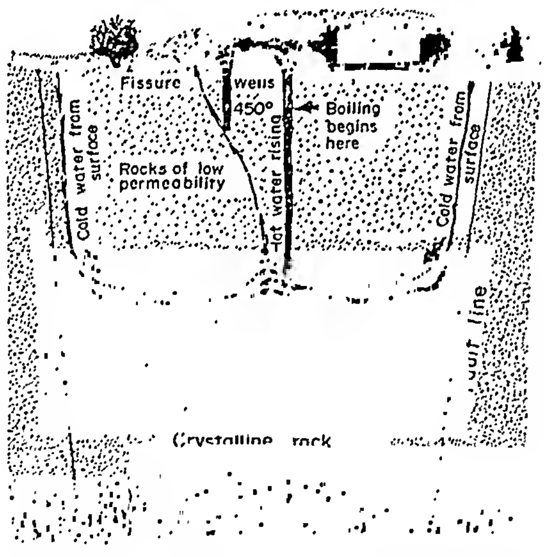

Fig. 15. Geothermal heat for electric power generation.

porous hot rock. For *vapor dominated* systems the geothermal reservoir exists at about 8000 ft and produces superheated dry steam. *Liquid dominated* systems are more prevalent than vapor systems and also more polluting. The reservoirs are found at relatively shallow depths (e.g., 3000 ft). The reservoir consists of a two-phase mixture of water (or brine) and steam under high temperature and pressure. Upon reaching the atmosphere, the hot water flashes into steam, often damaging and corroding the turbine blades. To compensate for this, new machinery is employed. The Magmamax Power Process uses a heat exchanger and a working fluid such as freon or butane. The Lysholm Rotary Expander comes in direct contact with the steam but the helical screw expander runs at a lower speed and with smaller radial loads than the conventional steam turbine.

The lower portion of the chart shows an impermeable crystal rock usually found at depths of 10 km. For these hot dry rock systems, two or more wells would be drilled into the rock; the rock would be fractured (e.g., hydro-fracturing, thermal fracturing, conventional and nuclear explosives), cool water would be injected in one well and the fluid heated by the rock would be extracted from another well. These systems are not currently economically competitive with other types of geothermal resources.

Geopressured systems consist of porous sand/clay mixtures isolated vertically by impermeable shale vertically and by faulting horizontally. Hot water at enormously high pressure is flashed to steam. Large quantities of dissolved methane are usually present in the reservoir.

SELECTED GEOTHERMAL OPERATIONS (Fig. 16)

In the United States, the potential capacity of the geysers is estimated at 1200–4800 MW. Mutsukawa in northeastern Honshu has a capacity of 20–27 MW and Otake and Kyushu have a capacity of 13 MW.

Location	Capacity (MW)	Cost (mills kWh	Potential capacity (MW)
Geysers-US	500	4.9	20 000–100 000 (US)
Larderello-Italy	400	3.2	—
Otake-Matsukawa-Japan	40	—	8 400–10 000
USSR	500	—	Very large

Others: New Zealand, Hungary, Algeria, El Salvador, Taiwan, Chile, Columbia, Yugoslavia, Iceland, Turkey, Mexico, Philippines, France.

Fig. 16. Selected geothermal operations.

The USSR has 11 projects relating to electricity generation, space conditioning, agriculture, and mining. The National Petroleum Council has estimated the following comparative costs of alternative power sources:

Hydropower	4.78 mills/kWh
Geothermal	5.25 mills/kWh
Nuclear	5.49 mills/kWh
Thermal	6.14 mills/kWh

FISSION REACTION

The standard fission reaction (Fig. 17) involves the capture of uranium-235 which then attains an excited energy state. The atom de-excites by splitting into smaller fission products (usually two) with the attendant release of energy and two or three neutrons which may be utilized to initiate another fission. The fission of U-235 is the primary source of energy in light water reactors (LWR—boiling or pressurized), while uranium-233 and plutonium-239 are the primary sources of energy in the high temperature gas cooled reactor (HTGR) and the liquid metal fast breeder reactor (LMFBR) respectively.

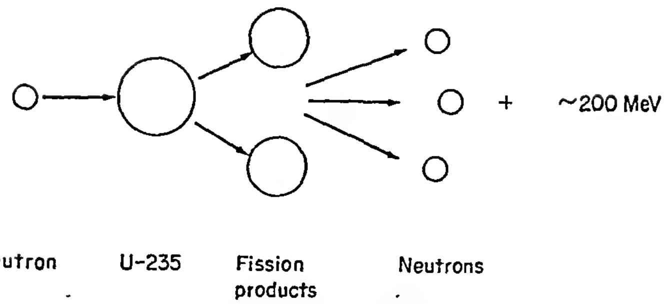

Fig. 17. Fission reaction.

WORLD RESERVES OF URANIUM

Figure 18 depicts the free world's resources of uranium as of 1971.* Each horizontal bar is divided into two segments, the left-hand portion showing the reasonably assured reserves

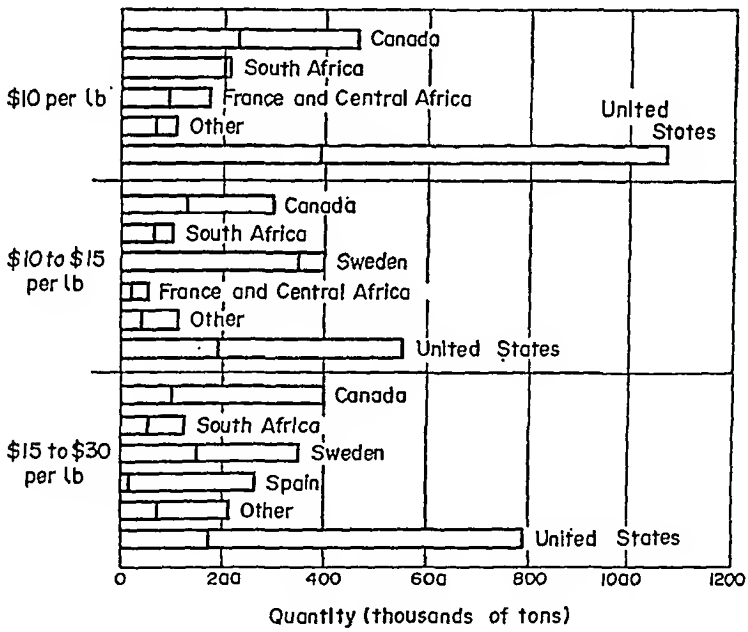

Fig. 18. World reserves of uranium.

(RAR) while the estimated additional reserves (EAR) constitute the right-hand segment. Below is a table summarizing the graph as well as presenting some more recent data.†

World Reserves (10^3 short tons U_3O_8)

	1971		1973	
	RAR	EAR	RAR	EAR
$10/lb	980	1060	1129	1194
$10–15/lb	790	730	884	823
$15–30/lb	560	1600	—	—

* OECD-IAEA report, August 1973.

† *Scientific American*, September 1971.

These data indicate that although fuel has been consumed in the two intervening years, reserves are higher for the later date as a result of additional exploration. As of 1973 the free world's reserves (RAR and EAR) of uranium ($\leq$\$15/lb) were 4030×10^3 short tons of U_3O_8.

WORLD URANIUM SUPPLY AND DEMAND: SHORT TERM

Figure 19 provides a picture of the short term supply and demand of uranium (in terms of U_3O_8). The cumulative demand represents the AEC's recent data* for a "most likely" situation. The supply information† from the OECD is slightly older but sufficiently valid

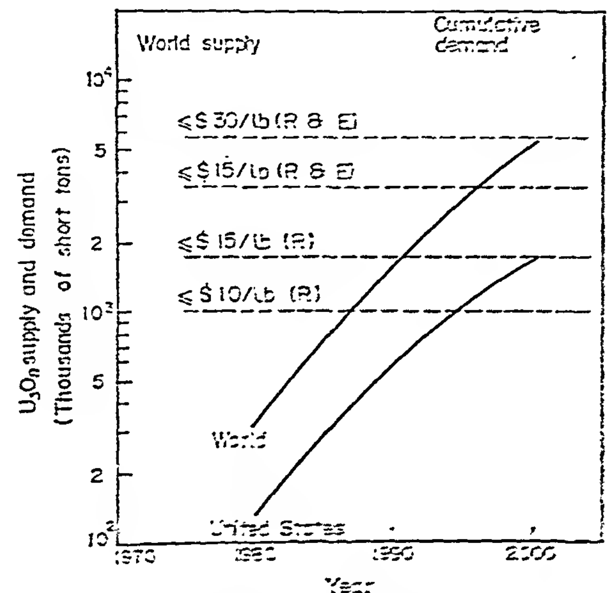

Fig. 19. World uranium supply and demand—short term. R = reasonably assured reserves; E = estimated additional reserves.

to make the point that relatively inexpensive uranium will last only a couple of more decades using a demand scenario highly dependent on light water reactors.

Since the AEC's "world" of cumulative demand includes centrally planned economies whereas the OECD's "world" of reserves does not, the apparent times to depletion would be shifted to the right, but not by more than one or two years, assuming the reserves of centrally planned economies are on the order of 40% of those of the rest of the world.

hypothesized that after 2006 no new LWR plants will be built and that after 2016 no new HTGRs are to be added. Advanced breeders, which are to begin in 2001, are to comprise 83% of new starts by 2016.

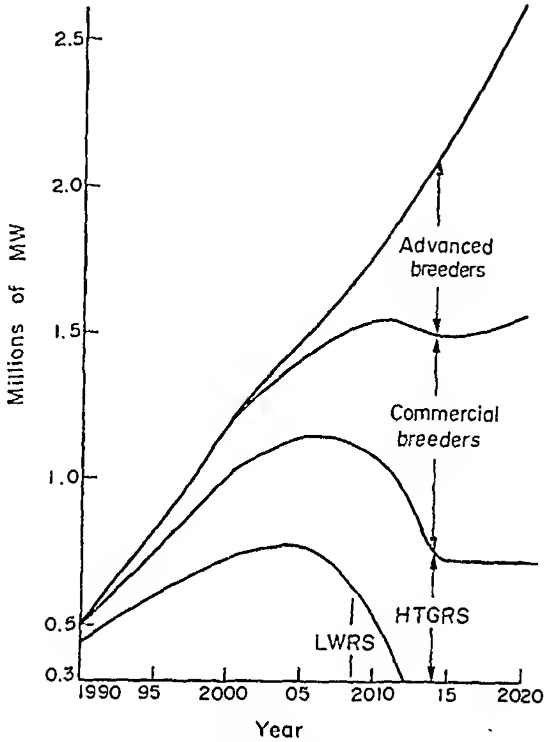

Fig. 20. Nuclear capacity by reactor type.

REACTOR CHARACTERISTICS

Figure 21 depicts several characteristics of different types of reactors which have a direct bearing on uranium reserves: the use of thorium and/or plutonium as alternative fuels, higher operating temperatures and plant efficiencies, and the utilization of breeders. It can

Reactor type	Fuel	Operating temperature	Plant efficiency	Comments
Light water (LWR)	UO_2	~600°F	33%	Pressurized and boiling, ~200 ST U_3O_8/yr
High temperature Gas cooled (HTGR)	UO_2/ThO_2	~1400°F	40%	Thorium blanket, ~100 ST U_3O_8/yr
Commercial breeder (LMFBR)	UO_2/PuO_2	~1200°F	38%	22 year doubling time, ~2 ST U_3O_8/yr
Advanced breeder	UC	~1700°F	42%	10 year doubling time, ~2 ST U_3O_8/yr

Fig. 21. Reactor characteristics.

be noted that the annual amount of U_3O_8 utilized by a 1000 MWe breeder reactor is two orders of magnitude less than that used in present-day LWRs of the same size.

FUSION REACTIONS

Nuclear fusion research is proceeding along the lines of two principal reactions—that involving deuterium reacting with deuterium or that concerning deuterium and tritium. While the latter combination produces more energy per reaction, the former involves constituents in higher supply (Fig. 22).

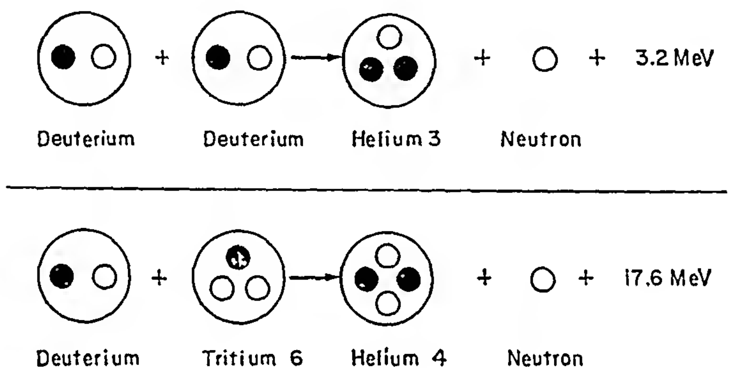

Fig. 22. Fusion reaction.

WORLD RESERVES OF LITHIUM

Earlier fusion success will most likely be achieved with the deuterium–tritium reaction because of the lower ignition temperatures involved. While supplies of deuterium appear to

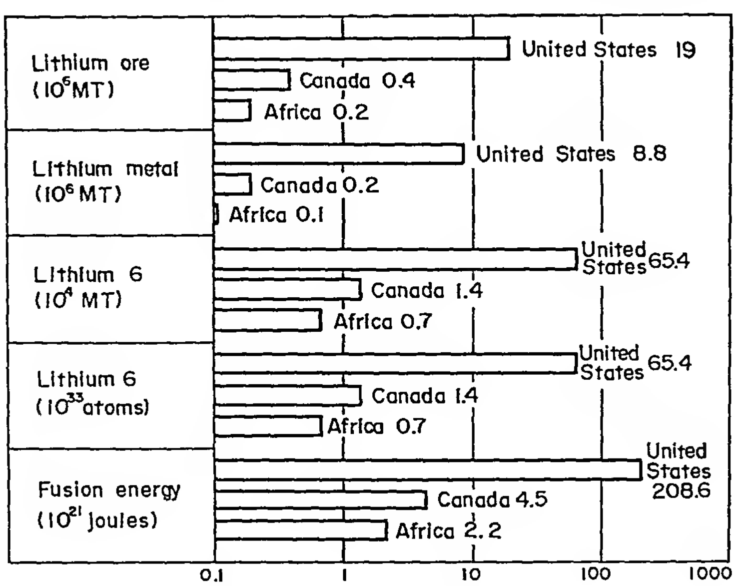

Fig. 23. World reserves of lithium.

be highly abundant (Fig. 23), natural tritium is in relatively short supply. Most tritium is, therefore, expected to be obtained from the neutron bombardment of lithium. Thus, until the deuterium–deuterium reaction becomes a reality, early fusion energy will depend upon supplies of lithium, in particular the Li-6 isotope.

GENERAL PROGRAM STRUCTURE FOR SOLAR ENERGY

The National Science Foundation's Solar Energy Program identifies the five program elements shown on the chart.

Cost of systems for *heating and cooling* of buildings are estimated to be $1000 for solar systems vs. $800 for conventional systems by 1985.
Cost of electricity produced by *solar thermal systems* are estimated at 40 mills per kWh by 1990 vs. 13 mills per kWh estimated for fossil-fueled turbogeneration.

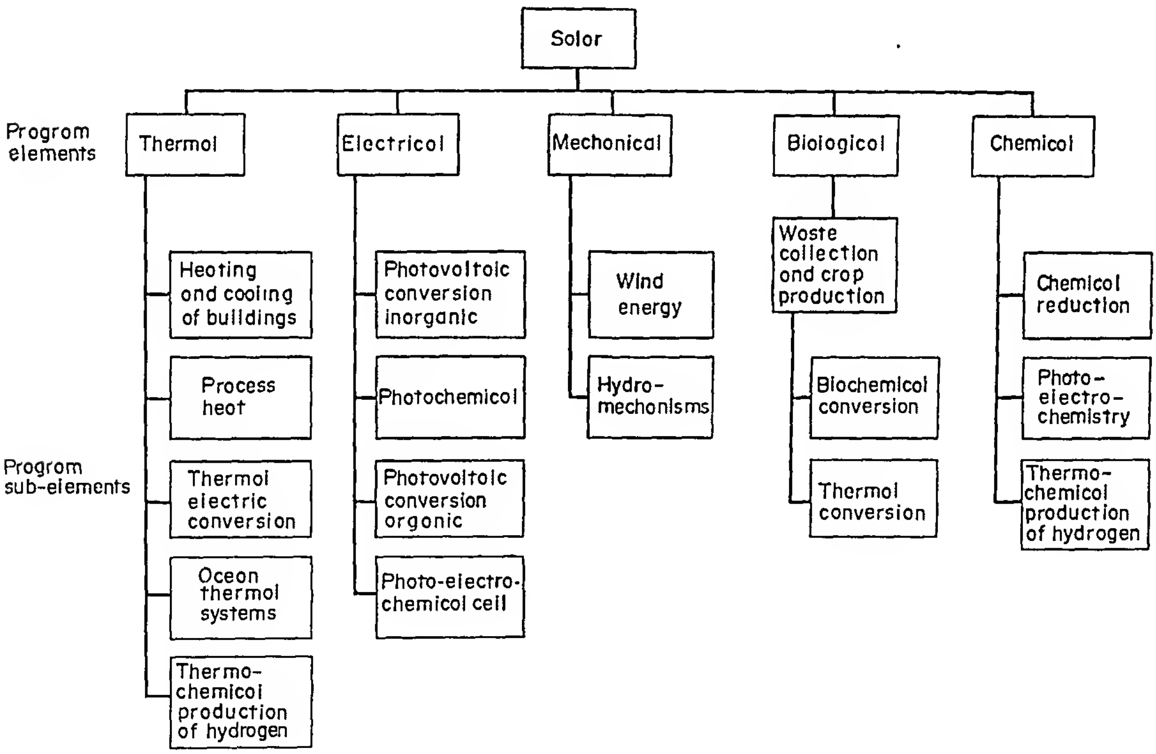

Fig. 24. General program structure for solar energy.

Ocean-based systems would produce electricity and hydrogen fuel at a cost of 10–15 mills per kWh in 2000, assuming capital costs of $200–400 per kWe capacity.
Photovoltaic conversion systems produce electricity and hydrogen using either silicon, cadmium sulfide, or gallium arsenide semiconductor solar cells. Silicon solar cells presently cost from $20 to $50 per peak watt. If design improvements are made and mass production introduced, costs could drop to $0.10 per peak watt by the year 2000.
Wind energy systems could be used to produce electricity and hydrogen and could also

pump and compress air for storage in reservoirs for use with gas to drive a gas turbine. These systems could provide electricity at a cost of from 5 to 8 mills per kWh by the year 2000. *Hydro* mechanisms would be used for pump storage.

Biological systems include: (a) combustion of organic wastes to produce heat, steam, and electricity; (b) pyrolisis and chemical reduction to produce oil; (c) hydrolysis to produce alcohol, and (d) fermentation and catalytic gasification to produce methane. Raising energy crops on 5% of the US land would provide sufficient BTU to meet 55% of today's national energy needs.

MINIMUM PROGRAM PROOF-OF-CONCEPT EXPERIMENT (POCE)

A two-cycle pumped system for solar thermal generation of electricity consists of:

Parabolic cylindrical reflectors with a sun tracking mechanism.

A liquid sodium or potassium cycle which involves heating the fluid as it passes through the collectors, cooling the fluid by means of a condensor and heat exchanger and pumping the cooled fluid back through the solar collectors.

An electrical generating cycle whereby water absorbs heat from the working fluid, is

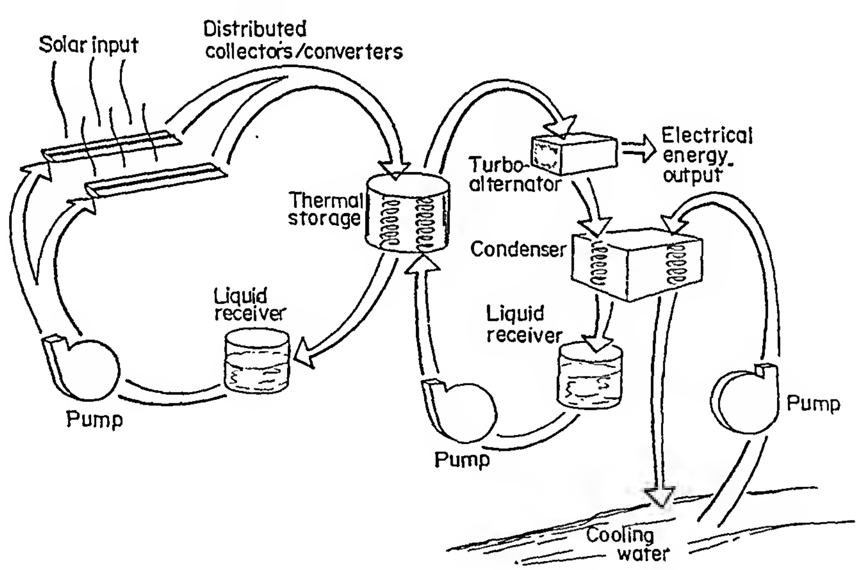

Fig. 25. Minimum program POCE.

converted to steam and drives a turbogenerator. The steam is condensed to water using rock or eutectic salts. The waste heat could be discharged using once-through cooling, ponds, or cooling towers, as required.

The Aerospace Corporation, University of Arizona, and Minneapolis Honeywell are building a 1 MWe unit requiring 30 acres of collectors to be operated on a pilot basis in FY 1979.

A total expenditure of $288 million over a five-year period is planned by the National Science Foundation for solar thermal electric development.

A 1000 MWe plant would require about 32 square miles of collector. Projected costs in the year 2000 are \$600 per kWe for the collectors and \$300 per kWe for the storage units.

HYDROGEN ELECTRIC UTILITY SYSTEM

With the exception of production of hydrogen and oxygen by photolysis, all functions shown on Fig. 26 could be performed if solar alternatives replaced the fusion power plant. Electricity would be produced by photovoltaic solar cells. Part of the output would be used to augment the electric energy capacity while a portion would be used to produce hydrogen and oxygen for direct sale to customers. In addition, some hydrogen would be regionally

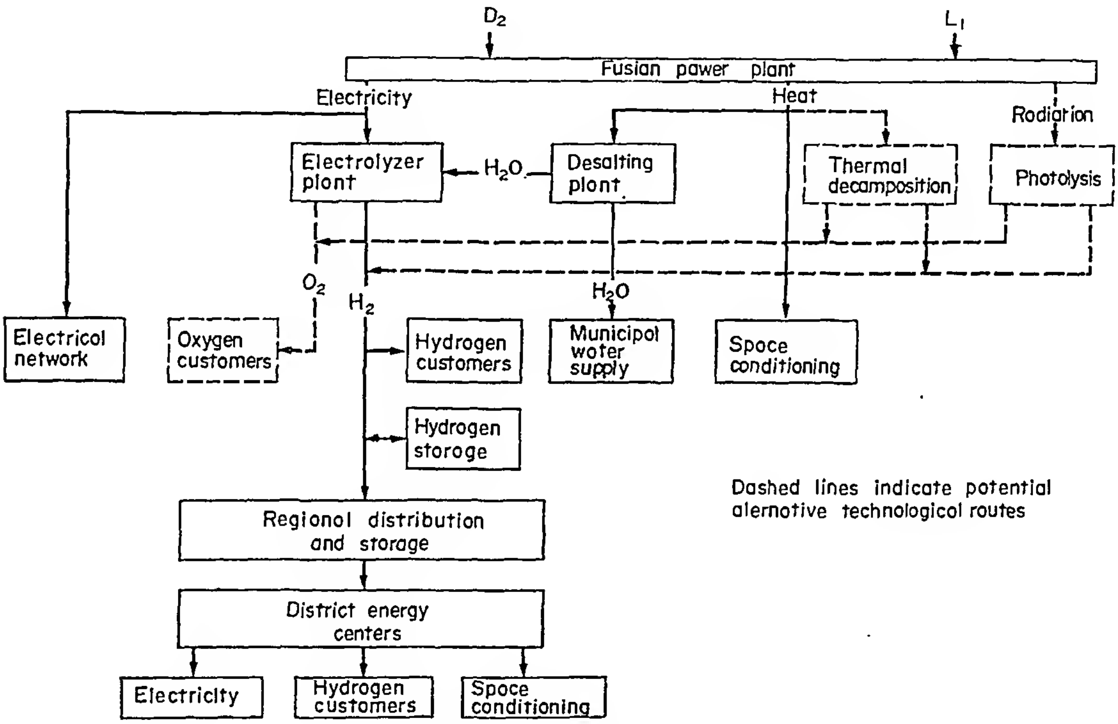

Fig. 26. Hydrogen electric utility system.

distributed, stored, and subsequently used for decentralized production of electricity from fuel cells and for space conditioning.

Heat energy from the sun could be used to desalinate water with the output either being sold to electrolyzer plants, used to augment municipal water supply, or used directly for agricultural purposes.

Solar heat could also be utilized directly for space conditioning. Thermal dissociation of water into hydrogen and oxygen would require a concentrator to generate the high temperatures required for this application.

RELATIVE COSTS OF TRANSMITTING HYDROGEN AND ELECTRICITY

Figure 27 shows that electrical transmission via underground cable is economically competitive with alternative transmission means for distances up to 20 miles. For distances

in excess of 200 miles, transmission of hydrogen is cheaper than 200 kV transmission of electricity. For distances in excess of 550–750 miles, transmission of hydrogen is less costly than transmission of electricity using 700 kV.

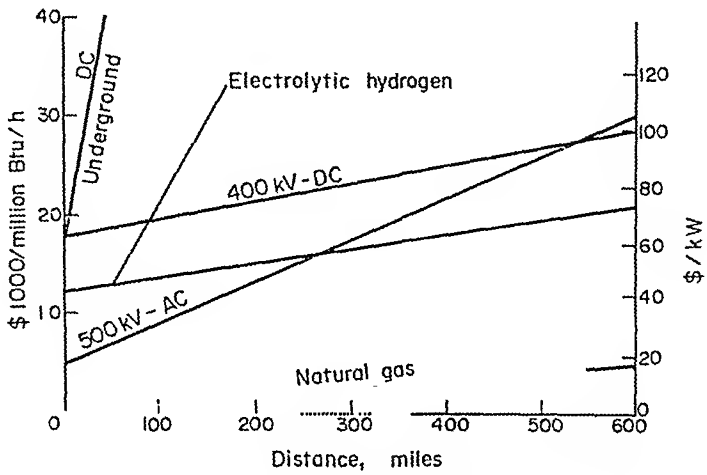

Fig. 27. Relative cost of transmitting hydrogen and electricity.

PROJECTED ECONOMIC VIABILITY RATIO (SOLAR/CONVENTIONAL)

Figure 28 shows the ratio of total annual costs (including fuel costs, O & M, and equipment amortization) of solar systems to the total annual cost of conventional systems that use fossil fuels. All solar systems with the exception of solar thermal, would be competitive with conventional systems in the period 2000–2020, if one is optimistic about the results of research and development and if fuel prices continue to escalate at real rates greater than 1% per year from 1977 to the year 2020.

	1985	2000	2020
Heating and cooling	1 to 1½	1 to 1¼	~1
Process heat	1½ to 2	1 to 1½	~1
Solar thermal	2½ to 3	2 to 2½	~1 to 2
Ocean thermal	1 to 1½	1 to 1¼	~1
Photovoltaic	6 to > 10	1 to 4	~1
Wind	~1	~1	~1
Organic materials	~1	~1	~1

Fig. 28. Projected economic viability ratio (solar/conventional).

TOTAL US ENERGY REQUIREMENTS AND POTENTIAL SOLAR ENERGY SUPPLIES

Figure 29 shows that seven types of solar supply systems could provide from 20 to 25% of total US energy requirements by the year 2000, based upon an increase in demand over current levels by a factor of about 2.25.

	YEAR			
Total US requirements	1980	1985	2000	
In watts (× 10^{12}) or in BTUs/yr (× 10^{16})	3 9	4 12	6 18	
Type of supply system	Per cent of total			General assessment
Heating & cooling of buildings	0.01	0.2	2	Ready now, but application slowed by institutional constraints
Process-heat	0	0.1	1	Some applications may be suitable for near-term. Needs R & T
Solar thermal	0	0.01	2 to 5	Promising, but may be difficult to operate and maintain. Needs R & T
Ocean thermal	0	0.01	1 to 5	Attractive, but technically difficult, and relatively expensive. Needs R & T
Photovoltaic	0	0.01	2 to 5	Real promise, but still relatively expensive. Needs R & T
Wind energy	0.01	1 to 3	5 to 10	Ready for application after some R & T
Organic materials	0.01	0.7	7	Waste conversion ready now; crops conversion needs R & T
Totals	0.03	2 to 4	20 to 35	

Fig. 29. Total US energy requirements and potential solar energy supplies.

ENERGY SCENARIOS

Figures 30–33 depict global scenarios for satisfying energy demands from three sources; fossil, nuclear, and solar. These are not offered as accurate prediction of what the future holds but rather are presented as reasonable options for satisfying potential future energy demands.

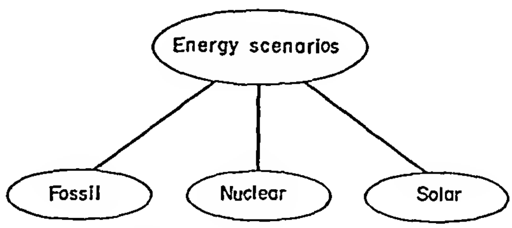

Fig. 30. Energy scenarios.

SCENARIO I—POWER CONSUMPTION

This scenario (Fig. 31) is based on the following estimated parameters:

Year	Global population (billions)	Per capita power consumption (watts)		
		US	Other developed[a]	Developing[b]
1970	3.6	11 000	4 000	600
2000	6.0	20 000	12 000	4 000
2100	12.0	60 000	50 000	32 000

[a] Other developed countries refers to the European nations, Japan, South Africa, Australia, Canada, Israel, and New Zealand.
[b] The developing nations include those in Africa, Middle East, Oceania, the Caribbean, and South America.

This is an optimistic scenario based on the premiss that the world economy expands vigorously and that suitable R & D is performed in the remainder of the century to insure a viable nuclear and solar technology out to the end of the next century.

Fossil fuels will satisfy 76% of the energy needs in the year 2000 with nuclear accounting

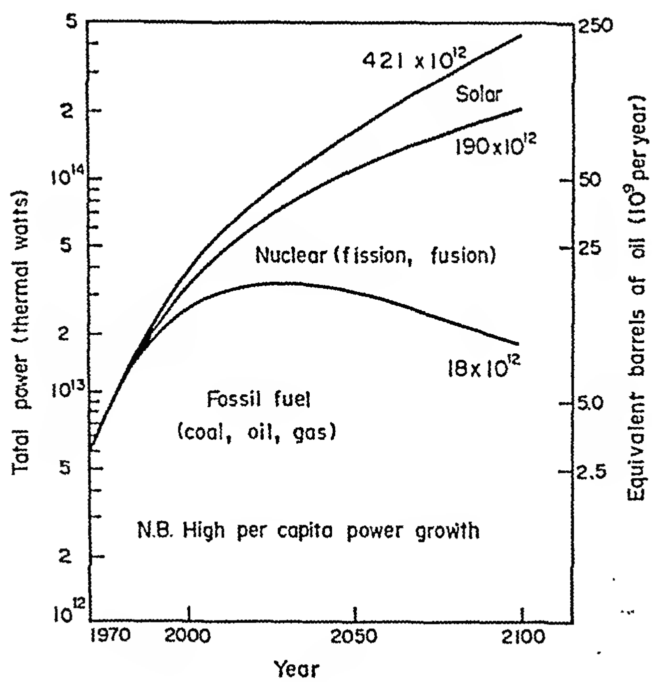

Fig. 31. Scenario I—power consumption.

for 20% and solar accounting for the remainder of the demand. Fossil-fuel consumption levels off out to 2050 and declines thereafter. Nuclear energy grows at an annual rate of 3% and accounts for 41% of the total demand by 2100. Solar grows at an annual rate of 5% during the next century and accounts for 55% of the total demand by 2100. While there is still a disparity among nations in terms of energy consumption by 2100, the developing countries would have narrowed the gap considerably relative to the present situation.

SCENARIO II—POWER CONSUMPTION

This scenario (Fig. 32) is identical to Scenario I out to the year 2000. The differences in per capita power consumption (watts) in the year 2100 are as follows:

	US	Other developed	Developing
Scenario I	60 000	50 000	32 000
Scenario II	50 000	25 000	12 000

Nuclear capacity is shown to increase at an annual rate of less than 2% per year from 2000 to 2075; over the last 25 years in the next century it would decline slightly, and account for 19% of the demand in the year 2000. Solar energy grows at the rate of 4½% per year from 2000 to 2100, accounting for 71% of the demand in 2100.

This scenario would produce less thermal discharge than Scenario I because fossil and nuclear sources combined provide a smaller percentage of a smaller total energy demand beyond 2000.

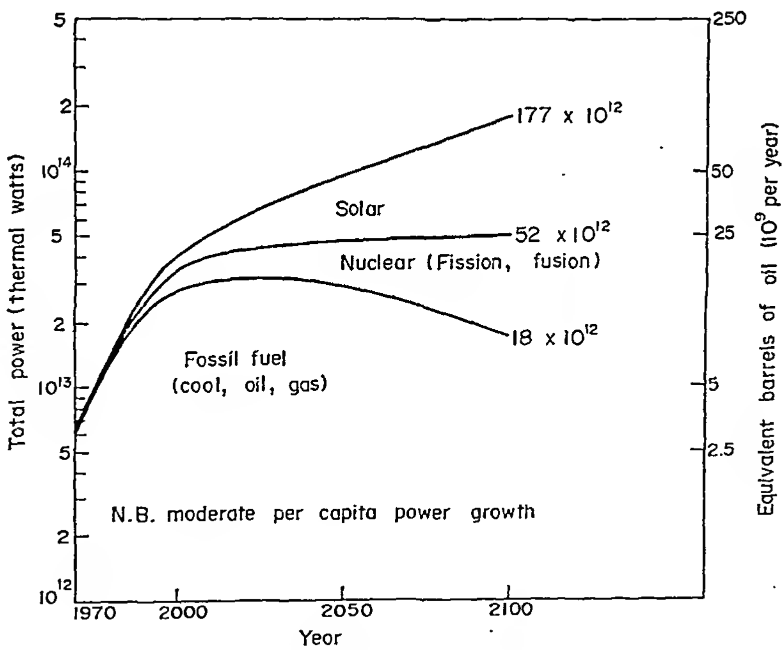

Fig. 32. Scenario II—power consumption.

CUMULATIVE ENERGY CONSUMPTION VERSUS RESERVES FOR SCENARIOS I AND II

The cumulative consumption for the fossil-fuel and nuclear power portions of both scenarios are presented in Fig. 33. The fossil-fuel reserves include gas, oil, and coal quantities for the entire world which are reasonably proven while the nuclear fuel includes both reasonably assured and estimated additional reserves of U_3O_8 at a price up to \$30 per

pound but excluding the centrally planned economies which could account for an additional 10–40% of U_3O_8. These are summarized below:

Fuel	Reserve quantity	Energy content (10^{15} BTU)
Natural gas	1763×10^{12} ft^3	1 820
Oil	642×10^9 barrels	3 590
Coal	7.64×10^{12} MT (2205 lb)	200 200
Fossil	—	205 610
Uranium (U_3O_8)	5.7×10^{12} ST (2000 lb)	2 070

The energy content of U_3O_8 was determined on the basis of the equilibrium operation of an LWR; i.e., 182 MT (200 ST) per year per 1000 MWe with an 80% load factor and a plant efficiency of 33%. The use of HTGRs would effectively "double" the reserves of U_3O_8 since the annual requirements are about 100 ST U_3O_8 for the same-sized reactor. A much more significant effective increase would be provided by the use of breeder reactors where the annual equilibrium feed requirements are on the order of 2 ST U_3O_8 per year.

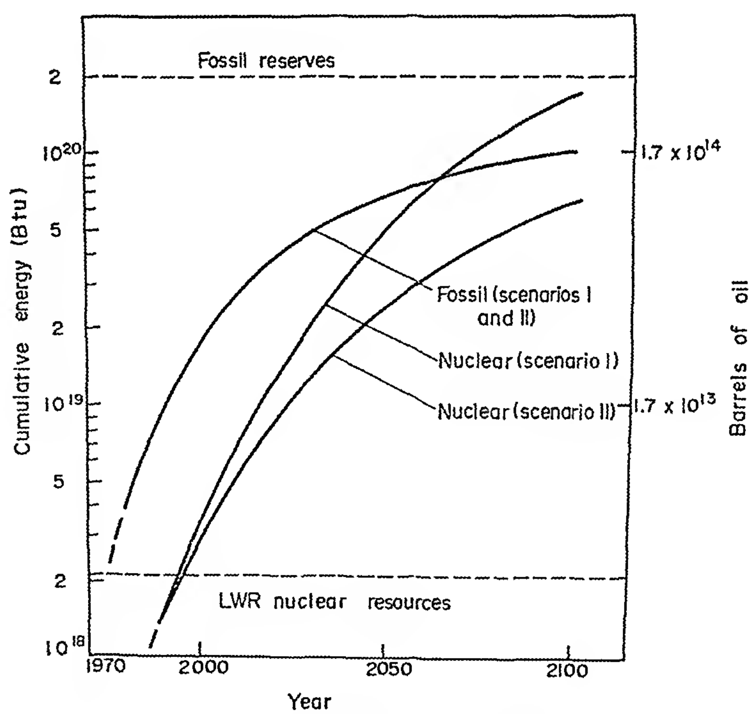

Fig. 33. Cumulative energy consumption versus reserves for scenarios 1 and II.

Therefore, unless actual uranium reserves are significantly increased or the higher priced fuel becomes more attractive, both nuclear scenarios suggest the introduction of the breeder in the late 1990s. It is further anticipated that fusion will become a working reality by the middle of the twenty-first century.

The use of "stored" (e.g., fossil fuels, fission, fusion) energy at a rate approximating 1% of the solar energy absorbed by the earth's surface (1% of roughly 1×10^{17} W or 1×15^{15} W) is likely to produce a 2–3°C rise in average global temperature and 10°C or more rise

at the poles. This temperature increase would be in addition to that caused by the carbon dioxide if fossil fuels were used. Therefore, it is desirable to limit the use of "stored" fuels to no more than 0.1% of the solar input or 1×10^{14} W and preferably to 0.01% of solar or 1×10^{13} W.

DISCUSSION

LAWAND: You mentioned that we could expect the 3000 nuclear stations in the next roughly 25 years. I'd like more precision on this—did I get this figure correctly? That's number one. Number two: What is the net energy production, quantified and scientifically evaluated? We have a number of plants in operation. I'd like to know what is the net energy production from these plants: the total sum inputs of energy going into the plant as compared to what comes out of a plant. Number three: Have we considered any material resource limitation? We've been talking about limitations to growth this morning. What about the construction materials in all these plants plus the distribution networks, etc., I'm talking about? I'll give you an example. In Canada now it's getting very difficult to obtain aluminum and we're an aluminum producer.

ZRAKET: First, you understood correctly. I did hypothesize 3000 nuclear plants in the year 2000 at a nominal rating of 1000 MWe per plant. I divided that roughly as follows—one-third would be built in the United States and two-thirds in the rest of the world. The current plans—which I don't think will be met because of a number of problems—are based on assumptions that we need to quadruple the use of energy in the next 30 years around the world as we go from 1.5 kW per capita average around the world to 6 kW per capita average around the world. The major increases will take place in the developing world.

Given these assumptions that means we have a factor of 4 increase roughly in energy use. I obtain that increase by doubling oil and gas production from today's figures, tripling coal production, and for nuclear energy, going to 3000 plants where in the United States we would generate 1.2 million MWs and the rest of the world 2.2 million MWs at a nominal 1000 MWs per plant gives you 3400 plants. As you know, the nominal efficiency of a nuclear reactor is about one-third ($33\frac{1}{3}\%$). Of course you lose some efficiency in mining the fuel for the reactor. Without going through all the steps, by and large, in terms of the raw energy that is in the ground, to what comes out the other end, the overall efficiency of most of these systems is about 5–10%, including isotope separation. The reason why that number is important, obviously refers to the last point I had made, namely that we should and can work very hard in conserving energy—all the way from the extraction process to the conversion process and then in the end use processes.

As far as materials are concerned, that is the subject of another workshop, as you know, but I don't believe that materials are short in nature. I don't think nature or the supply of materials is the problem, but our knowhow in building the alloys needed to have these systems operate at the required temperatures and reliability regimes is lacking. The single biggest constraint technically to achieving advanced coal-conversion systems and nuclear and nuclear systems, for example, is the materials problem.

CAPRIOGLIO: If I understood it correctly the difference between Scenarios I and II concerning the amount of solar energy that was taken into account, was due to thermal pollution consideration. Now I am somewhat surprised by that, since by using solar energy one is not in fact helping much in terms of thermal pollution because one is changing the albeds of the earth. In other words, one is taking more heat out of the sun and distributing it as energy available to the population. If you add to that the efficiency of the process I don't think there is any advantage in using solar energy with respect to any other primary source of energy, fossil, or fissile.

ZRAKET: I don't think that's entirely true. It is true that the deployment of solar energy collectors, that is the collectors themselves, will have an effect on the albedo and we don't really know how great that effect will be, but I don't think that it vitiates the fact that the net heating overall of the earth is increased significantly less in comparison to fossil fuels if we are careful in what collectors we use and where they are placed. If you leave out the change that the collectors themselves make to the albedo, then there is no net thermal heating of the earth using terrestrial-based solar energy systems. Now you do, for example, transfer the heat from where you collect to where you use it, so you end up with local changes. But what we're worried about now is not the transfer from one part of the earth to another part of the earth, but whether or not overall on spaceship earth, if you will, the net heating effect is as close to zero as possible.

LEWIS: I think we had better not continue this discussion at the moment. Let me just say that I think a good point was made by Dr. Caprioglio but we need to see this well documented. I was doing a little mental arithmetic and this goes for Dr. Zraket too—and I have a feeling he was using a very high albedo for the earth when he says that 12 000 million people at 50 thermal kW were going to be producing 1% of the energy from the sun. I think the figure is closer to 0.5%.

ZRAKET: Yes. That's well taken.

THE NEW ENERGY SYSTEM AND THE PROJECT SUNSHINE

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INTRODUCTION

For the survival of mankind on this planet, the energy and its resources which maintain our social, economic, and technological systems have been recognized as the most important and critical problems of the present day. Constituting a characteristic feature of diversity, the present energy system might increase its complicated phase and accelerate the difficulty in finding the solution when serious efforts will be neglected.

The limiting of fossil fuels including oil, coal, natural gas, etc., has been announced by many scientists to be almost within 50 years or about 190 Q where one Q corresponds to 3.35×10^7 MW/year ahead. Meanwhile, one might say that no critical shortage of energy may be expected in terms of long range energy supply and demand on a global scale. The possibilities on nuclear fission and fusion energies, and alternative sources of energy such as solar, ocean, wind, geothermal, and others have been investigated throughout the world, while some of them are still in earlier stages of research and development.

Most of the energy resources such as nuclear, geothermal, solar, ocean, and wind energies have been localized in a sense, and the transportation problem should be taken into consideration in the global analysis of future energy systems in addition to the nature, quantities, and distribution of energy resources. The limit of growth has often been discussed recently, and this sophisticated problem includes many conflicting phases such that developed countries may have enough time and funds to develop alternative sources of energy until the exhaustion of fossil fuels, while many developing countries have to face the difficulties in R & D on new sources of energy and in finding the solution prior to an expected energy crisis. However, very few detailed analyses on the problems and predictable factors related to zero or minus growth have been made scientifically up to the present, and it seems very likely for mankind that he has to decelerate the rate of growth in the near future, closely related to the analysis on carrying capacity of his environment. The above-mentioned points should carefully be taken into account under the political, social, environmental, and psychological viewpoints as well as the background of economy, population, and energy resources on the international basis. The international cooperation on problems of these types might be feasible and accepted, while the international consensus on energy supply and demand must be requested in the later part of R & D on energy resources.

BRIEF REMARKS ON ENERGY TRANSPORTATION PROBLEMS

Generally, the energy transportation must be considered as a part of the processes on discovery of energy resources, acquisition, transportation, conversion, and consumption, all of which largely depend upon the politics and diplomatic problems. Safety factor and environmental aspects might be followed with the respective processes and increase the weight in economic evaluation of the transportation system. Efforts to reduce the transportation costs have been focused on the expansion of scale, simplification in the transportation techniques, concentration of energy density, etc. The intrinsic nature of energy consumption systems in future might also result in the change in varieties of energy resources towards the production of electricity.

The future energy transportation system may vary from those of the present ones, in which five kinds of technology have been developed. A vessel, railway, motor truck, pipelines, as well as electric wires are the existing transportation techniques in pursuit of scale merit on an economic basis.

Because of limitation by environmental capacity, the future energy conversion system might be constructed some distance from an industrialized area, and accordingly request the long distance energy transportation system. Unfortunately, transmission of electricity is one of the most expensive methods in energy transportation systems, although UHV and other transmission methods have been under investigation.

There might not be strong objection on that the promising energy resources at and after the year 2000 might possibly be assigned to the nuclear and solar energies on the earth. In the future total energy system, hydrogen fuel technology might join after both the nuclear and solar engineering. The transportation system for SNG and NG which might play the important role in the medium range energy system will be available for hydrogen transportation.

Further, the energy-storage system will be closely related to the transportation system because of the localization of energy resources and the time lags in transportation and consumption. R & D on storage of electric energy, superconductive technology, microwave transmission, and other novel technologies might be of great use in future energy transportation. On the contrary, an exact knowledge on the relationship between the carrying capacity of our environment and net energy to be consumed should be requested.

THE PROJECT SUNSHINE

It is a real privilege to introduce the new energy R & D project being sponsored by the Japanese Government as one of the patterns to develop alternate sources of energy.

The Agency of Industrial Science and Technology, Ministry of International Trade and Industry of the Japanese Government, has inaugurated the Project Sunshine from the fiscal year 1974. The background and purpose of this project are as follows:

1. Energy is the source of human activities and the clean environment is an oasis for human activities.
2. For the last decade oil consumption in Japan has grown 3.4 times to that in 1960 with average annual increase rate of 11%.
3. More than 73% of energy supply in Japan depends on imported oil, while stable supplies of low cost oil can no longer be expected.

The project itself has been started from 1974 with the fiscal budget of 2.44 billion yen (40.0 million FF) and trillions of funds will be invested up to the year 2000.

Nuclear energy is excluded in the project because the R & D systems on nuclear fission and fusion energies have already been established by the Agency of Science and Technology under the Prime Minister's Office in Japan.

Under the present circumstances, an energy project in the long term sense has been directed up to the year 2000 by many countries and governmental bodies, and the new energy system and the transportation mechanism should be discussed on the basis of provision on variation of energy resources and social structure, R & D on energy science and engineering, economic growth, and, finally, the international relationship on the global scale.

L'ENERGIE GEOTHERMIQUE: LES UTILISATIONS ACTUELLES ET LES EXPERIENCES EN COURS POUR LES DEVELOPPEMENTS FUTURS

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LES UTILISATIONS ACTUELLES

L'apport de l'énergie géothermique aux nécessités montiales de l'énergie est aujourd'hui très petit.

Un peu plus d'un million de kW installés (v. Tab. 1) en mesure de produire une dizaine de milliards de kWh/an. Il s'agit de 2% environ des besoins électriques actuels: le pétrole équivalent économisé correspond à trois millions de tonnes/an, soit 0,5% de l'énergie primaire.

Il est plus difficile, en raison du caractère incomplet des informations, de dresser le bilan de l'énergie géothermique utilisée dans le monde pour des applications non électriques (chauffage, climatisation, procédés de distillation et de fermentation, séchage d'algues et de farines fossiles, industrie papetière, etc.): les informations du "Symposium des Nations Unies sur le Développement et l'Utilisation des Ressources Géothermiques", qui a eu lieu à Pise en 1970 et quelques publications récentes (Leardini, 1973; National Energy Authority, Reykjavik, 1973, etc.) indiquent que l'on dispose pour ces applications de 12 000 Tcal/an, soit $1{,}2 \times 10^6$ tonnes/an de pétrole équivalent (v. Tab. 2).

Au total, donc, 4,2 millions de tonnes/an de pétrole équivalent, soit 0,7% de l'énergie primaire utilisée à présent dans le monde.

Les sources géothermiques prédominantes sont la vapeur naturelle sèche ou surchauffée (150–260°C) à des pressions qui ne depassent pas les 10–11 ata (Armstead, 1970).

Des reserves plus vastes sont contenues dans les sources d'eau chaude ou de vapeur très humide. La quantité de chaleur emmagasinée dans les roches chaudes et sèches de la lithosphère est encore plus marquante.

Pour ce qui concerne le coût de l'énergie géothermique par rapport aux autres sources, on peut faire quelques considérations à partir des informations relatives à la situation du 1970.

A The Geysers, le coût de l'énergie produite grâce à la vapeur géothermique a été 0,0053 US $/kWh net.

Par comparaison, le coût du kWh produit par une centrale thermique alimentée en fuel-oil

TAB. 1. Puissance géothermoélectrique actuellement installée, en voie d'installation ou de projet

Pays—Régions—Localités	Puissance installée (MW)			Puissance en voie		Achèvement prévu
	Partiale	Totale	%	de installation	de projet	
Italie						
— Larderello: région boracifère	380,1	—	—	—	45	
— Région du Monte Amiata	25,5	405,6	36,1	—		Prochaines années
— Serrazzano—Torre Alfina	—	—	—	15	15	1975-1976
United States						
— The Geysers: groupes 1 + 10	396	396[1]	35,2	—	—	—
— „ „ : groupes 11 + 15	—	—	—	106[1]	406[1]	1974-1977[1]
— Salton Sea et Brady's Hot Springs	—	—	—	60[2]	200[2]	1978
Nouvelle Zelande						
— Wairakei	192	—	—	—	—	—
— Kawerau	10[3]	202	18	—	—	—
— Brodadlands	—	—	—	—	120[3]	1976
Mexique						
— Pathé	3,5	—	—	—	—	—
— Cerro Prieto (I^ phase)	75[1]	78,5	7	—	—	—
— „ „ (II^ „)	—	—	—	—	75[1]	1976
Japon						
— Matsukawa et Otake	33	33	3	—	—	—
— Hachimantai	—	—	—	10[4]	—	1974
— Onikohbe—Hatchobaru 1	—	—	—	75[4]	—	1975
— KaK Konda 1	—	—	—	50[4]	—	1976
— Hatchobaru 2—Kak Konda 2	—	—	—	—	300[4]	Prochaines années
URSS						
— Pauzhetka	5	—	—	—	—	—
— Paratunka	0,75	5,75	0,5	—	—	—
— Kamchatka	—	—	—	—	100[5]	Prochaines années
Islande						
— Namafjall	3	3	0,2	—	—	—
El Salvador						
— Ahuachapan (I^ phase)	—	—	—	30	—	1975
— „ (II^ „)	—	—	—	30	30	1978
Guatemala						
— Moyuta—Azulco	—	—	—	—	90	Prochaines années
Indonesie						
— South Sulawesi	—	—	—	—	250[6]	Prochaines année
Philippines						
— Leyte, Tongonan, Burawen	—	—	—	—	100[7]	Prochaines années
— Tiwi—Luzon	—	—	—	—	10[8]	1980
Totals	1123,85	1123,85	100	376	1741	—

(1) Geothermal Hot Line. (2) Koenig, 1970. (3) Smith, 1970. (4) IGEA, 1972. (5) Naymanov, 1970. (6) Radja, 1970. (7) Geothermics, 1972. (8) Geothermics, 1974.

à US $/tonne s'est chiffré à 0,01 US $ et celui du kWh produit par une centrale nucléaire à 0,012 US $ (Robson, 1974).

L'exploitation des centrales géothermoélectriques italiennes a abouti à des resultats analogues (Di Mario, Leardini, 1974).

En Islande, le "Reykjavik Municipal District Heating Service" alimente en eau chaude à 80°C les maisons de la capitale, à un prix de 0,16 US $/Gcal: la chaleur utilisée par les usages est en moyenne 42 kcal/kg. Cela comporte un prix de 3,8 US $/Gcal, dont 1,3 pour

TAB. 2. Chaleur géothermique disponible et utilisée dans des domaines diverses (Tcal/an)

Pays	Utilisations	Actuellement		Disponible dans les prochaines années
		disponible	utilisée	
Hongrie	Chauffage de locaux. Applications dans l'agriculture	3.420[1]	1.200	7.000[1]
Islande	Chauffage de districts—Applications dans l'agriculture—Séchage des diatomites	3.000[2]	1.750	4.000
Mexique	Production d'eau douce	50	30[3]	200
Nouvelle Zelande	Chauffage et conditionnement de locaux. Production de pulpe de bois et de papier	950[4]	500	2.000
URSS	Chauffage de locaux. Chauffage de serres, du sol. Balnéothérapie	3.500	1.750[5]	18.000[5]
United States	Chauffage et conditionnement. Extraction de produits chimiques	1.000[6]	830	3.000
Autres pays	Chauffage et conditionnement. Applications dans l'agriculture, extraction de produits chimiques, balnéo thérapie, production de eau douce, etc.	80	40	1.500
	Totals	12.000	6.100	35.700

[1] Boldizsàr, 1970. [2] National Energy Authority, 1973. [3] De Anda *et al.*, 1970. [4] Smith, 1970 [5] Lokchine e Dvorov, 1970. [6] Koenig, 1970.

les forages, les collecteurs et les réservoirs et 2,5 dollars à titre de frais de distribution (Palmason, Zoëga, 1970). Si l'on utilise du fuel-oil à 25 US $/tonne, avec un rendement de 65%, le coût de production et de stockage de l'eau chaude serait 3,8 US $/Gcal (le même que le prix total et à peu près trois fois le coût *de production* de la chaleur géothermique).

Toujours en Islande, l'installation pour le traitement des diatomites, en service régulier depuis quelques années près du lac Myvatan, a utilisé de la chaleur endogène à un coût de 2 US $/tonne de matière sèche, contre les 12 US $ nécessaires pour traiter une tonne de diatomite avec la chaleur provenante du fuel-oil (Lindal, 1970).

L'installation géothermique de chauffage urbain de la ville de Sgezed (Hongrie du Sud) a produit de la vapeur à un coût de 3 US $/Gcal, contre 11 US $/Gcal pour la chaleur dérivant d'autres sources (Boldizsàr, 1970).

En conclusion, le coût de l'énergie géothermoélectrique en 1970 a été la moitié du coût de l'énergie provenant de sources thermiques ou nucléaires, tandis que la chaleur terrestre utilisée pour des applications non électriques a coûté 1/3–1/6 de celle fournie par le fuel-oil. L'écart s'est accentué aujourd'hui en raison de la crise pétrolière, qui a plus que triplé le coût des combustibles traditionnels dans les pays importateurs.

PERSPECTIVES FUTURES

Les tableaux 1 et 2 résument les développement prévus dans l'utilisation des fluides naturels respectivement pour la production d'électricité et pour des usages non électriques.

La puissance géothermoélectrique installée dans le monde doublera et, peut-être, triplera dans les cinq prochaines annés et atteindra un total de plus de 3000 MW, si on construit les installations déjà projetées dans les différents pays. Les utilisations actuelles, dont la fig. 1 donne les cycles les plus significatifs, s'assortiront dans les années à venir de cycles à

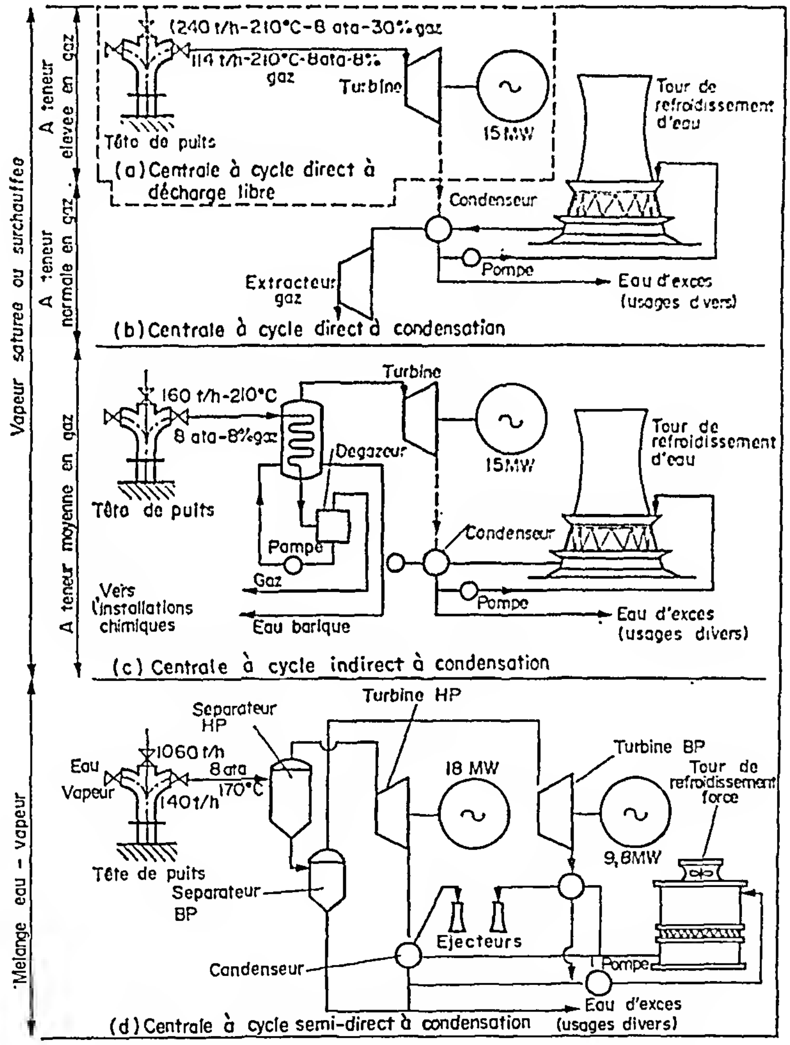

Fig. 1. Utilisation électriques actuelles des fluids endogènes.

fluides à bas point d'ébullition (fréon, isobutane, etc.) et d'installations thermogravimétriques particulières (v. fig. 2) permettant l'exploitation, à des fins électriques, même d'eau chaude à 80–200°C (Hansen, 1961; Pessina *et al.*, 1970).

Les prévisions que font quelques auteurs à plus long terme semblent moins probables.

Aux USA, par exemple, un rapport récent (Hickel, 1972) envisage des puissances électriques de 132 000 MW et 395 000 MW, respectivement pour 1985 et 2000, que l'on peut

obtenir à l'aide d'un vaste programme de recherche et de développement des ressources géothermiques. Toutefois des autres auteurs font remarquer que, pour réaliser le programme de 132 000 MW électriques, les 685 millions de dollars prévus ne sont pas suffisants.

Supposant qu'on puisse atteindre aussi à l'avenir les importants résultats de The Geysers (60% de forages productifs, 5 MW/forage productif), il faudrait effectuer, en le temps de onze années, 42 000 forages, à un coût moyen par forage de 240 000 US \$ (y compris les

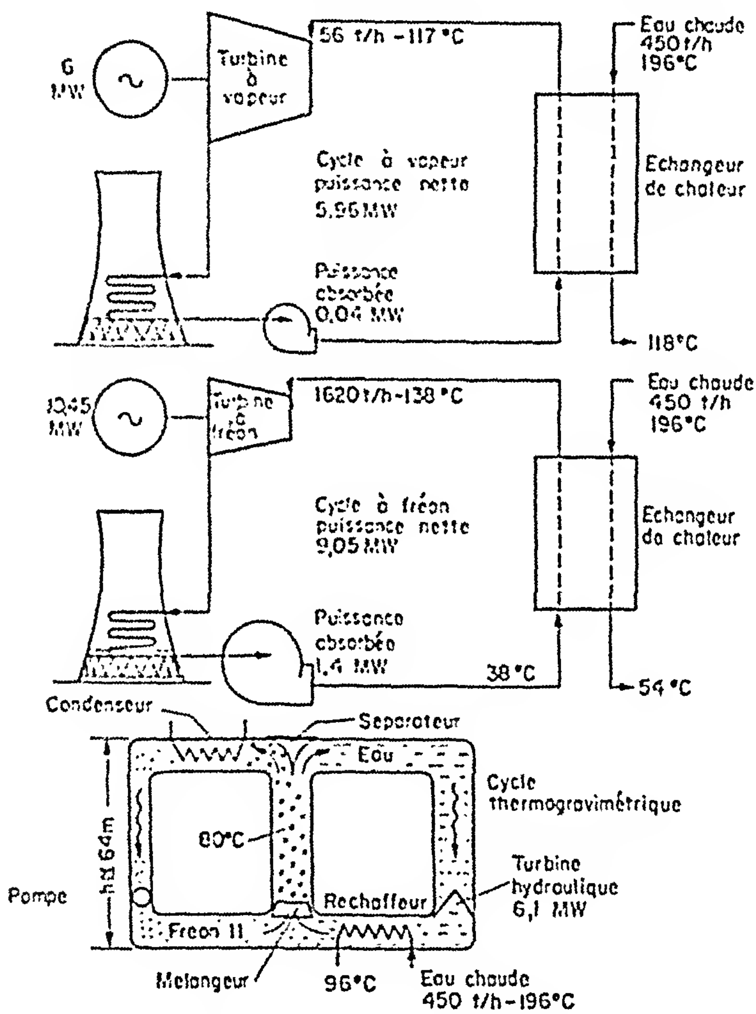

Fig. 2. Possibles utilisations de l'eau chaude géothermique.

frais d'exploration): d'où une dépense totale de l'ordre de 10 milliards de dollars seulement pour produire le fluide nécessaire (Robson, 1974).

Le problème se pose aussi de savoir comment les compagnies de forage engagées dans l'exploration géothermique aux USA et réalisant une certaine de forages/an, pourront et voudront (étant donnés les forts risques) faire front à des engagements 40 fois supérieurs. Il conviendra également de contrôler sur le plan expérimental (la chose la plus importante, à notre avis) si les forages futurs produiront du fluide au débit unitaire actuel.

Au *Japon*, les scientifiques ont estimé le développement géothermique futur à 30 000–140 000 MW (Finn, 1972).

L'expérience italienne conseille à cet égard des prévisions moins optimistes pour les raisons suivantes:

— il est possible (des dizaines de cas se sont produits à Larderello) de trouver des puits ayant des débits initiaux supérieurs à 300 t/h de fluide et capables d'alimenter des groupes électrogènes qui depassent 30 MW: mais ces puissances tombent rapidement avec le temps, notamment avec l'intensification des forages dans la même région.
— au cours de l'exploitation d'un champ vaporifère, il faut non seulement trouver le fluide pour de nouvelles installations mais encore pourvoir à la diminution naturelle des puits en exploitation.
— si l'on étend la zone de forage, en général le pourcentage des forages productifs, le débit par forage et la disponibilité de fluide par km^2 tombent;
— l'intensification des forages dans la même zone augmente la profondeur moyenne (et donc le coût) des forages.

Les données les plus significatives du développement géothermique dans les zones de Larderello, Travale et Monte Amiata (v. Tab. 3) confirment ces considerations:

TAB. 3

Situation géothermique italienne au 31 Décembre	1950	1955	1960	1965	1970
Soufflards en exploitation (n°)	95	150	171	180	199
Debit total de fluide (t/h)	2220	2600	2840	3340	3500
Debit par forage productif (t/h)	23,4	17,3	16,6	15,8	17,6
Zone explorée (km^2)	5	10	50	150	215
Debit par km^2 (t/h)	440	260	56,8	22,3	16,3

Puits achevés: productifs (n°-%)	72-65	51-60	41-38	32-41
stériles (n°-%)	39-35	34-40	67-62	45-59
Perforation effectuée (ml)	67.850	69.110	98.080	72.610
Profondeur moyenne des nouveaux puits (ml)	672	823	908	943
Increment de fluid par puit (t/h)	3,8	2,9	4,6[1]	2,1

[1] Cas particulier, dû à l'explosion du forage PC/8—Monte Amiata (310 t/h).

Pour ce qui concerne les autres applications des fluides endogènes, on peut prévoir les mêmes développements futurs que pour la production d'énergie électrique (v. Tab. 2). Il s'agit de l'utilisation des fluides géothermiques ayant une température peu élevée (environ 50°C) jusqu'à des fluides provenants de gisements à haute température (220–250°C). A côté du chauffage et de la climatisation de locaux civils et ruraux (habitations, serres, étables pour l'élevage de bétail), on propose une série d'applications qui vont du chauffage des terrains agricoles à l'élevage d'anguilles et de crocodiles, du séchage du bois, des algues et des farines fossiles à la production de papier, de la production d'eau douce (ou lourde) de l'eau saumâtre à l'extraction de produits chimiques des mêmes eaux (chlorure de sodium, bromures, magnésium, bore, souffre, etc.). Les systèmes, combinés (par exemple, production d'électricité et chauffage, production d'eau douce et extraction de minéraux, etc.) sont envisagées avec un intérêt croissant et on peut estimer que les fluides géothermiques à haute enthalpie seront de plus en plus rationellement employés non seulement pour la production d'énergie électrique, vu le coût peu élevé de la chaleur endogène.

NOUVELLES ETUDES: LA "CHALEUR SECHE"

Des calculs et des expériences récents ont montré que deux tiers de la chaleur terrestre sont contenus dans les roches profondes et le reste dans les fluides qui les imprègnent (Facca, 1970): d'où l'importance que prendrait l'extraction de la chaleur des roches ("chaleur sèche").

A une dizaine de km de profondeur, on pourrait trouver des roches à une temperature relativement élevée, avec un gradient de température normal (30°C/km), auquel correspond en moyenne un flux calorifique terrestre par conduction de 1,5 cal/cm^2 sec. Mais des régions étendues montrent des gradients (et donc des flux de chaleur) trois, quatre fois supérieurs (Goguel, 1970); on peut y trouver des roches chaudes à 250–350°C, à une profondeur de 2–4 km, accessible grâce à la technologie actuelle de forage.

Supposant que la chaleur spécifique de roches compactes, telles que celles qu'on trouve à ces profondeurs (granits, schistes, etc.), soit 0,25 kcal/kg °C et que la densité respective soit 2,65 kg/dm^3 (Harlow et Pract, 1972), un km^3 de matière, refroidie de 350° à 300°C, fournirait 35×10^{12} kcal, soit environ 40 milliards de kWh thermiques.

Moyennant les cycles pour l'utilisation électrique proposés récemment et comportant des turbines à vapeur et des turbines alimentées en fluides à bas point d'ébullition (isobutane, fréon, etc.), on prévoit des rendements totaux de l'ordre de 20%. Par conséquent, par la chaleur de un km^3 de roche refroidie de 50°C, on peut produire 8 milliards de kWh, correspondant à peu près à la production annuelle géothermoélectrique dans le monde.

Si à la chaleur terrestre on ajoutait d'autres sources de chaleur (par exemple l'énergie nucléaire), les rendements et les résultats seraient meilleurs.

L'idée de développer artificiellement l'énergie géothemique en l'associant à des explosions conventionnelles ou thermonucléaires très profondes, dans des régions à gradient thermique élevé, a été suggérée pour la première fois par un Français (C. Rougeron, 1956). Le projet Plowshare de l'Atomic Energy Commission, avec l'explosion souterraine effectuée en Septembre 1957 sur un terrain expérimental du Nevada, semble avoir entraîné des résultats encourageants, si bien que le Dr. Edward Teller, le créateur de la bombe H, a affirmé que "l'énergie tirée de cet explosif est beaucoup plus économique que celle de ses concurrents, énergie atomique ou pétrole, au prix d'aujourd'hui" (*L'Express*, Septembre 1973).

Afin que le champ géothermique artificiel puisse fonctionner, il importe qu'il y ait en profondeur des canaux ou des failles à l'intérieur desquels l'eau à chauffer, souterraine ou pompée de la surface, puisse circuler.

Cela, selon bien des scientifiques, n'arrive pas parce que les fractures produites par l'explosion atomique se ferment presque immédiatement et leur réouverture artificielle augmenterait trop le coût.

Par conséquent, le projet s'est transformé: on envisage de capter la "chaleur sèche" des roches d'une manière plus simple. La fig. 3 schématise le nouveau procédé suggéré par le "Los Alamos Scientific Laboratory".

Le projet veut reproduire artificiellement le phénomène qui dans le champ géothermique classique se produit naturellement. Il s'agit en fait d'introduire, moyennant un puits avec un tubage approprié, un fluide vecteur (eau) dans des terrains à des profondeurs adéquates; de créer, en profondeur, des fractures artificielles permettant un meilleur échange de chaleur entre les roches chaudes et l'eau de circulation; de reporter à la surface, moyennant un deuxième forage parallèle au premier, le fluide vecteur chauffé; d'utiliser cette chaleur de la meilleure façon, tant pour la production d'électricité que pour d'autres applications.

Une publication très intéressante du Los Alamos Scientific Laboratory montre la séquence des opérations pour réaliser le projet:

a) *Sélection du site:* il s'agit de choisir des zones avec des situations géologiques-géothermiques favorables; on doit notamment contrôler l'existence de couches profondes peu perméables et de gradients thermiques supérieurs à la moyenne.

b) *Réalisation du premier forage* (plus profond), avec les diamètres ordinaires des forages géothermiques (~9″) et des profondeurs variables selon la thermalité des terrains (ordre de

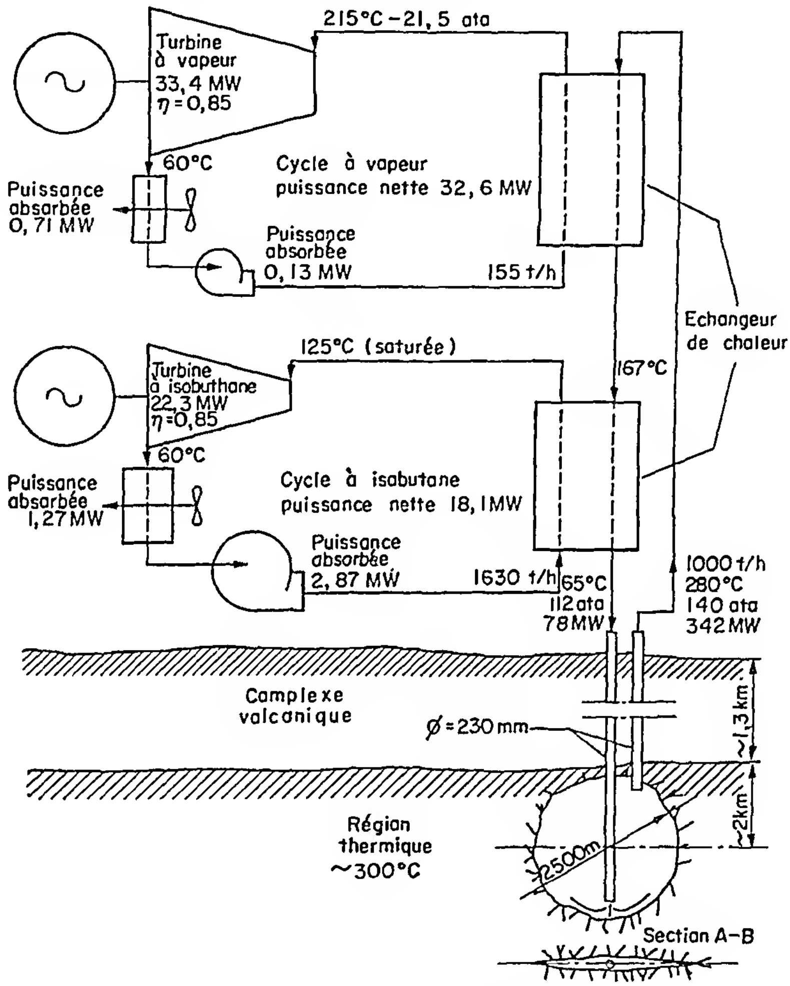

Fig. 3. Possible utilisation de l'énergie géothermique.

grandeur 3–4 km). La réalisation du puits, avec un tubage bien cimenté, fournira des éléments sur les caractéristiques géologiques et thermiques des complexes traversés, très utiles au développement futur du projet.

c) *Fracturation initiale* des roches au fond du forage, par la méthode de l' "hydrofracturing" utilisée très souvent par l'industrie pétrolière et qui, essentiellement, consiste à pomper en profondeur de l'eau à haute pression (environ 200 kg/cm^2 à la tête du forage); la pression de la pompe, ajoutée à la pression hydrostatique de la colonne de perforation, provoque des contraintes qui fracturent les roches de fond du puits. Des enquêtes mathématiques, confirmées par des expériences directes, ont mis en évidence que la fracturation

initiale est en théorie représentée par une fissure circulaire, orientée verticalement, à section elliptique, dont on parlera ensuite.

d) *Réalisation du deuxième forage* (moins profond), à effectuer à plusieurs dizaines de mètres de distance du premier, avec des diamètres analogues au précédent mais éventuellement sans tubage dans la dernière partie. Si l'on utilise les techniques du forage dévié on devra atteindre la cavité produite par la fracturation initiale des roches et établir la communication avec la colonne d'eau pressurisée du premier forage.

e) *Fracturation finale des roches:* une fois que l'on a établi la communication entre les deux forages, on achève l' "hydrofracturing" de la zone au fond du puits jusqu'aux dimensions nécessaires.

f) *Circulation de l'eau pressurisée:* elle doit être entamée à l'aide d'une pompe: à mesure que l'eau se chauffe en profondeur, on établit un système à thermosiphon par différente densité du fluide dans la colonne descendante et ascendante qui porte à la surface l'eau pressurisée, dans des quantités considérables (Smith, 1973).

g) *Utilisation de la chaleur à la surface:* comme il l'a été fait noter, la transformation de la chaleur d'eaux chaudes pressurisées en énergie électrique peut-être effectuée par des cycles binaires, comprenant des échangeurs de chaleur, des turbines à vapeur et des turbines alimentées en fluides à bas point d'ébullition.

Afin d'éliminer les pertes de fluides et d'éviter la pollution atmosphérique, les turbines prévues sont équipées de condenseurs à air. Ces sont évidemment des installations plus onéreuses que celles en service jusqu'ici, mais elles donnent lieu à des rendements si élevés qu'elles devraient compenser la complexité supplémentaire d'installation.

Le coût de l'énergie qu'on peut obtenir, grâce à ces systémes, de la "chaleur sèche" est estimé à 4,7 et 8,0 mills/kWh utilisant respectivement des roches chaudes à 300°C (et des centrales de 100 MWe à double cycle) et des roches à 175°C (et des centrales de 100 MWe à isobutane). Ces coûts se rapportent à 1970 et sont comparables à 11,8 mills/kWh et 13,3 mills/kWh, pour l'énergie nucléaire et, respectivement, pour l'énergie thermoélectrique produite dans la même période dans la zone de New York (Brown *et al.*, 1972).

Quelques considérations sur ce projet:

— grâce à la technique actuelle de perforation géothermique, on peut surmonter les difficultés relatives aux forages profonds. A Larderello aussi on a effectué des forages de plus de 2700 m, avec des diamètres minimum de 9⅝s (environ 245 mm). Les techniciens de Los Alamos prévoient en outre l'application industrielle du nouveau système de perforation qu'ils ont inventé en 1960 à l'échelle de laboratoire ("the rock-melting drill"). Le développement de réacteurs nucléaires compacts ainsi que de circuits thermiques spéciaux font entrevoir la possibilité de fondre des terrains et des roches et d'effectuer des forages ayant un diamètre de plusieurs mètres et profonds de quelque dizaine de kilomètres, à des coûts particulièrement bas (Robinson *et al.*, 1971);
— de même, la fracturation de roches profondes ne devrait pas présenter des imprévus importants, si l'on utilise les techniques standard appliquées à présent et relativement peu coûteuses. Halliburton, par exemple, fait état des résultats positifs obtenus par l' "hydrofacturing" dans des forages profonds de 3700–4500 m dans le Texas occidental (Halliburton Service, 1971);
— en revanche, la réalisation du circuit fermé de circulation de l'eau s'avère comme plus complexe. Tout en ayant recours aux techniques de forage dévié, il apparaît difficile d' "aller pêcher", par le deuxième forage, la fracture provoquée par l' "hydrofrac-

turing", très étendue verticalement mais très restreinte (quelque dizaine de centimètres) en section horizontale. Quelques-uns pensent à des explosions profondes, peut-être conventionnelles, pour faciliter la liaison hydraulique entre les deux forages;

— il semble impossible de transférer la chaleur dans la quantité désirée (227 millions de kcal/h soit 264 MW) par un seul système forages-fracture. Si l'on assimile la fracturation profonde à un cylindre de hauteur minime, avec l'axe horizontal, on peut imaginer que le changement de chaleur de la roche à l'eau s'effectue le long des deux bases du même cylindre, placées sur des plans verticaux parallèles et très proches l'une de l'autre. D'après des calculs qui ne prétendent indiquer qu'un ordre de grandeur, si l'on suppose que le coefficient d'apport thermique est 6000 kcal/h m^2 °C et que la différence moyenne de température roche-eau soit 150°C, la surface de contact est environ $2{,}52 \times 10^6$ m^2 et le diamètre de chaque face (supposée plane) est 2,5 km comme prévu.
Mais, compte-tenu du refroidissement progressif de la couche de roche en contact avec l'eau et de la faible conductibilité des roches ($6{,}2 \times 10^6$ kcal/s cm °C), une zone fracturée avec un diamètre de 1 km permettrait l'extraction de $1{,}3 \times 10^{13}$ kcal pour vingt ans, soit une puissance thermique de 89 MW (Robinson *et al.*, 1971): avec un diamètre de fracture de 1,25 km, la puissance disponible monte à 139 MW.
Il faudrait toutefois deux systèmes puits-fracture pour fournir les 264 MW thermiques nécessaires à l'installation génératrice prévue et cela mettrait en doute les résultats économiques expliqués jusqu'ici. Les scientifiques américains espèrent que le phénomène de rupture des roches en voie de refroidissement par contrainte thermique pourra faciliter d'une manière considérable l'élargissement de la fracture initiale et le transfert de la chaleur terrestre (Harlowe Pract, 1972).

— des pertes d'eau dans des éventuelles failles des couches profondes ne permettraient pas de réaliser le projet, puisqu'il serait impossible de maintenir les pressions nécessaires à la circulation du fluide vecteur. En outre une centrale électrique telle que celle à la fig. 3, pourrait produire de l'énergie électrique pour une communauté typique de 60 000 habitants: cette communauté utilise, en moyenne, 18 000 m cubes d'eau/jour. Une perte de 10% de l'eau utilisée dans l'installation géothermique priverait la communauté du 13% de l'eau, en général potable, dont elle a besoin.

CONCLUSIONS

L'énergie géothermique fournit à présent un apport très modeste (0,7%) aux besoins de l'humanité: par le triplement prévu et possible des installations de production délectricité et de chaleur pour d'autres applications (chauffage, climatisation, distillation, séchage, etc.), l'apport en pourcentage de la géothermie doublera dans la prochaine décennie.

Quelques prévisions à plus long terme (500–600 GW électriques, soit environ 10% de la puissance installée prévue dans le monde pour l'an 2000) ne semblent pas réalisables avec les moyens actuels de recherche et d'utilisation de la chaleur endogène. La réalisation d'unités alimentées en chaleur sèche des roches, portée artificiellement à la surface, pourrait apporter une contribution décisive au développement de la géothermie. Les expériences en cours sont très hardies et témoignent de la capacité d'imagination de l'Homme: pour en obtenir des résultats appréciables au point de vue industriel, il faudra, toutefois, y travailler nombre d'années.

SUMMARY

The contribution geothermal power gives to meet energy requirements in the world is minimum: it is roughly equal to 4.2 tons of oil, namely 0.7 for each thousand of the primary energy resources which are now utilized in the world.

Up to now the prevailing geothermal sources have been superheated or slightly humid steam (150–250°C) and pressurized waters (150–230°C). Greater reserves of endogenous fluids are to be found in hot water or wet stream; even greater is the amount of heat contained in dry hot rocks.

In 1970 geothermoelectric energy costs were half those recorded in thermal or nuclear energy production, whereas costs for the non-electric utilizations of geothermal fluids ranged from one-third to one-sixth as compared with fuel oil costs. Lately the difference in costs has become more evident on account of the well known crisis in oil production and distribution: costs of conventional fuel oil quadrupled in importing countries.

Therefore, industrialized and developing countries have become more and more interested in geothermoelectric energy. Within the next five years the total geothermal capacity in the world is expected to double and perhaps to triple, totalling more than 3000 MW if the scheduled new installations are put in operation.

As regards prospects for the future development of the non-electric utilizations of endogenous fluids, they are at least not different from what is expected from their exploitation for electricity generation. In non-electric applications use is made of both low temperature (around 50°) and high temperature (200–250°C) geothermal fluids. In addition to space heating and airconditioning in urban and rural areas (houses, greenhouses, stables, etc.), endogenous fluids may be utilized for many other purposes: from farming heating to fish and alligator hatching, from drying processes (wood, seaweed, diatomite flour) to paper milling, from the desalination of brackish water to the extraction of the chemicals there contained (sodium chloride, bromide, magnesium, boron, sulphur, etc.).

From the investigations that have been carried out lately, it results that two-thirds of the terrestial heat are contained in deep, hot, dry rock layers and the rest in the endogenous fluids there circulating; it is therefore self-evident how important the system for harnessing heat from deep rocks would be for a better development of geothermal power production.

The idea of developing geothermal energy artificially by harnessing the heat given by conventional or thermonuclear explosions in deep rock layers was suggested for the first time by Mr. C. Rougeron in 1956; the Plowshare project of the Atomic Energy Commission consisted in the underground explosion of an atomic bomb and was carried out in the Nevada Desert in September 1957. On the basis of the successful results achieved on that occasion, Dr. E. Teller, the inventor of the H-bomb, stated that "the energy harnessed by means of this kind of explosive is much cheaper than the one which can be obtained by petrol or by nuclear power stations".

However, to accomplish this project it is necessary to make the artificial geothermal field, that is to say the chimney, in a rock having fractures through which the underground water or the water pumped down from the surface may freely circulate.

According to some experts that cannot be done in the above-mentioned project since the fractures produced by nuclear explosion are self-sealing and their artificial reopening would be too expensive.

As a consequence, the original project has been transformed and today's efforts are aimed at harnessing the heat content of hot dry rocks in a way which may be easier. A new project,

which has been proposed by the Los Alamos Scientific Laboratory, aims at the artificial reproduction of a phenomenon which is naturally produced in conventional geothermal fields. The way of acting is to introduce from the surface a fluid, for instance water, by means of a well having an appropriate depth, to wit 4–5 km; rocks must have a high temperature and be completely waterproof. At the aforesaid depth, fractures will then be produced allowing a better exchange of heat between the hot rocks and the circulating water which will be carried to the surface through a second well, which is parallel to the first. The hot fluid may then be transformed into electricity or utilized for other purposes.

After describing the operations which are necessary for the development of this project and the difficulties to be coped with, the authors come to the conclusion that today geothermal energy gives a negligible contribution to the world energy requirements: geothermoelectric plants are expected to triple and their capacity both for electricity generation and heat-requiring processes (space heating, air conditioning, distillation and drying processes, etc.) to double in the next 10 years.

Some long term forecasts, such as 500–600 GWs equal to 10% of the total geothermal capacity to be installed in the world in the year 2000, are not likely to be fulfilled on account of the current inadequate means of investigation on and utilization of endogenous fluids.

Should power plants be fed by the heat flow of dry rocks, artificially carried to the surface, the increase in geothermal production would be considerable. The experiments which are by now being carried out are very difficult and advanced and show the inventive power of men; many years are still to pass before achieving appreciable results from geothermal power exploitation in industrial activity.

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DISCUSSION

LEWIS: Before inviting a question, let me make a comment. We should certainly look to hydrogen as the best storable first stage from the spare electrical energy. As we know, in large scale electricity production one of the problems is that the energy is not readily storable. We can store some by pumped water storage, but we are keenly looking into putting it into hydrogen for its use in various ways. Because it is very important to keep the generators turning, we do not want to start and stop the electrical generators—that is extravagant. So we're very keen on these new processes.

DATTA: I agree with Dr. Caprioglio that hydrogen definitely is one of the materials we have to look for as a source of energy, but of the two methods you have described or would suggest, one is electrolysis which is fairly developed, and the other is the chemical method by closed cycle. We in our country tried to do something in these respects and the economics did not work out favourably, at least for the conditions in our country. I should be more exact: the cost of one unit of power (kWh) is, say, about 10 paise (one-tenth of 1 rupee), corresponding to about 0.2 cent (French); even under these conditions, it does not work out economically using hydrogen as a source of power. So such a situation has led us to search for other ways of producing hydrogen. One such method is the heating of water in the presence of lithium nitrate; another method is the photolysis of water using plasma radiation, and also the biochemical method; we are concentrating on producing methane rather than hydrogen; we have been trying to do all these, but I know that we have a long way to go. But we feel that one of these might bring down the cost to an acceptable value. Tentatively, in a preliminary way, we consider, one of these two methods may perhaps be satisfactory for India.

CAPRIOGLIO: Obviously this subject would allow us to discuss methods for hydrogen production for the whole day at least. But I should like to qualify what I've said in the sense that I've limited myself to those methods that would leave us a hope of being ripe before the end of the century, let's say in 25 years. In other words, methods that exist already, or are on the verge of existing on the laboratory scale, so that one would need something like 15 years for industrial development. I've quoted these two lines—electrolysis and close cycle thermal reactions. Concerning photolysis, I think this a promising route if you take much longer periods of time, and it would probably require fusion one day to do it properly. Concerning the straightforward heating of water in the presence of whatever separation method—physical, chemical—one can think of, I'm a bit more skeptical, but I must confess that I know too little about the process that is being followed in India to make any judgment. So, first, I would rather have a discussion on the method itself before giving an opinion. On the economics side, I've said that the electrolysis looks very poor at present, and I think what you have said confirms this. Electrolysis looks very poor if one adds to the capital costs of the electrical plant, the rectifiers because one needs direct current, and then the electrolytic cells. If you add poor efficiency to that, this is really hopeless. I think, however, it is worth pursuing the development because of the progress likely to happen in the field of electrolytic cells once the modern technology of fuel cells will be applied. I think that one order of magnitude in power density is possible and increases in efficiency from 65 to 80 or 85%. And that may make a difference. Concerning the chemical cycle, the main uncertainty is the capital cost of the chemical plant. We don't know enough about that. Generally speaking, I'm rather optimistic—for one reason: if you take all existing chemical plants for producing whatever product you can think of, they cost very similar prices to the unit energy handled. So I don't expect a hydrogen plant to be much different from that. Admittedly, this is a very rough argument. The other reason for being optimistic is that the market is very easily accessible because it involves a spread of values for hydrogen. It's not like making electricity, where you are either below or above making electricity with fossil fuel. This was the trouble with nuclear energy for something like 10 or 15 years. Because there was a threshold: either you were in or out. In the case of hydrogen this is not the case because there is a large fraction of the market that already uses very expensive hydrogen. That is relatively easy to conquer. The more you can get down with your price, the bigger the share of the market you can reach. And so on and so forth. Where can you arrive? I don't know. You may stop only at the "chemical" hydrogen alone, but that only would be worthwhile of a serious and even expensive development.

ZRAKET: You may have covered this in your remarks, Doctor, but I may have missed it in the translation. Given that we may get an economically viable process for production of hydrogen in the future, and given that we will develop fuel cells so that we can use them in production of electricity, would you say something about the possibility of actually using the hydrogen to produce methane because of the infrastructure we will have built up in using methane in many areas? Do you find that a useful thing to think about?

CAPRIOGLIO: I have not covered this. In fact the field is so vast that it was impossible to talk about everything. I think that the future of methane lies very much more in coal than in hydrogen. I can imagine for a very long time to come that the natural gas system will survive the shortage of natural gas through synthetic natural gas made by coal—maybe with nuclear help, but that's another matter. Hydrogen will only reach the pipeline stage at the end of its career. When hydrogen will be cheap enough to be worthwhile to build a large hydrogen pipeline network, this means that hydrogen will have achieved the rock bottom value for energy, competitive with any other. At that time it would make no sense to mix methane with it. This, at least, is my opinion.

LA FUSION THERMONUCLEAIRE CONTROLEE

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I. INTRODUCTION

Un bref exposé sur la fusion thermonucléaire contrôlée peut paraître une gageure puisqu'il s'agit d'un sujet déjà très vaste quoiqu'encore relativement récent. On peut mesurer sommairement l'effort mondial de recherche dans ce domaine en disant que plusieurs milliers de chercheurs s'y consacrent depuis 15 à 20 ans dans au moins une douzaine de grands laboratoires répartis dans le monde. Il ne peut donc être question de faire ici, même un résumé des résultats obtenus. D'ailleurs, le sujet de cette conférence invite à prendre beaucoup de recul. Si l'on considère l'ensemble des actions souhaitables pour l'avenir de l'humanité, les recherches sur la fusion contrôlée n'en constituent évidemment qu'une très petite parcelle. De ce point de vue très élevé, il est clair qu'il faut surtout apprécier les chances d'aboutir et les délais nécessaires et voir quelles seraient les principales caractéristiques de la nouvelle source d'énergie qui serait ainsi ouverte. C'est ce que nous tenterons de faire dans cet exposé.

II. PRINCIPE DE LA FUSION THERMONUCLEAIRE CONTROLEE

Essayons d'abord de rassembler rapidement les notions les plus utiles sur le principe de la fusion contrôlée.

Comme dans le cas maintenant classique de la fission, il s'agit de produire de l'énergie avec des réactions nucléaires. Mais au lieu d'avoir recours à des noyaux lourds comme l'uranium, on cherche à utiliser des noyaux légers en s'inspirant de la source d'énergie des étoiles. En pratique le combustible envisageable sur terre ne peut être constitué que par deux isotopes de l'hydrogène: le deuterium et le tritium. Les réactions possibles sont alors l s suivantes:

$$\mathrm{D} + \mathrm{D} \rightarrow \mathrm{T} + p + (1{,}0 + 3{,}0)\ \mathrm{MeV}$$
$$\mathrm{D} + \mathrm{D} \rightarrow {}^{3}\mathrm{He} + n + (0{,}8 + 2{,}4)\ \mathrm{MeV}$$
$$\mathrm{D} + \mathrm{T} \rightarrow {}^{4}\mathrm{He} + n + (3{,}6 + 14{,}1)\ \mathrm{MeV}$$

Les deux branches de la réaction (D,D) sont à peu près également probables. Les deux nombres indiqués entre parenthèses sont les énergies moyennes emportées par chacun des

produits de la réaction; la somme des deux donne l'énergie libérée par la réaction. Comme nous le verrons plus loin, la réaction (D,D) offrirait en principe une solution idéale au problème de l'énergie à très long terme puisque le deuterium se trouve en quantité quasi-illimitée dans l'eau naturelle d'où il est facile à extraire. Malheureusement, à énergie cinétique égale des noyaux, la section efficace de la réaction (D,D) est environ 100 fois plus faible que celle de la réaction (D,T). Aussi, dans la phase actuelle des recherches, n'envisage-t-on que la réaction (D,T) pour une production pratique d'énergie.

Le principal inconvénient de cette réaction est évidemment que le tritium n'existe pas dans la nature. Il peut être produit artificiellement en absorbant des neutrons dans du lithium et la réaction (D,T) fournit justement le neutron nécessaire pour régénérer le tritium brûlé. Il y a donc là un principe possible d'énergie nucléaire à partir de deux éléments naturels, le deuterium et le lithium.

Il faut noter aussi que dans la réaction (D,T) la plus grande partie de l'énergie libérée (en fait 80%) apparaît sous la forme de l'énergie cinétique du neutron, ce qui est une forme d'énergie pour le moins inhabituelle.

Voyons maintenant brièvement comment il est possible de produire effectivement cette énergie. La seule solution est de suivre l'exemple des étoiles et de porter le combustible à des températures de dizaines de millions de degrés pour qu'il réagisse. En deux mots, le problème fondamental de la fusion contrôlée est alors de maintenir le mélange de deuterium et de tritium dans les conditions requises de température et de densité, de façon que la combustion thermonucléaire produise plus d'énergie qu'il a fallu en dépenser pour "allumer" le mélange. C'est la solution de ce problème qui fait l'objet des recherches actuelles et deux voies tout à fait différentes sont explorées:

— la première est la voie du confinement magnétique: on utilise des champs magnétiques puissants comme récipients pour contenir ou "confiner" le combustible en profitant du fait qu'il se trouve à l'état de gaz complètement ionisé ou "plasma";
— la deuxième peut être appelée la voie des explosions: on utilise un combustible très dense subissant la fusion très rapidement avant qu'il ait le temps de se disperser, compte tenu de son inertie. On espère pouvoir réaliser cette situation en irradiant un grain solide de mélange deuterium–tritium à l'aide de lasers très puissants.

III. LA FUSION PAR CONFINEMENT MAGNETIQUE

Essayons maintenant de faire un bilan rapide des recherches dans la voie du confinement magnétique. Ces recherches occupent les laboratoires de fusion contrôlée depuis 15 à 20 ans, aux Etats-Unis, en URSS et en Europe occidentale. Malgré son énorme difficulté, le problème du confinement magnétique a été mené maintenant assez près de sa solution. Il faut noter que cette difficulté n'a pas un caractère principalement technique, mais qu'elle est au contraire de nature tout à fait fondamentale. Le confinement d'un plasma par un champ magnétique était, il y a 20 ans, un grand chapitre vide de la physique qu'il a fallu écrire patiemment. La physique du quatrième état de la matière que constituent les plasmas était tout entière encore dans l'enfance et les laboratoires de fusion contrôlée ont dû prendre son développement en charge dans une large mesure.

Pour pouvoir évaluer l'importance des résultats obtenus, il faut poser le problème en termes quantitatifs, au moins approximatifs. Les conditions physiques requises pour la combustion thermonucléaire portent principalement sur trois grandeurs: la température du

combustible, sa densité et le temps de confinement. Pour la réaction (D,T) la température doit être entre 50 et 100 millions de degrés. Le temps de confinement doit être assez long pour que le combustible soit brûlé dans une proportion suffisante avant d'être dispersé. Comme la vitesse de réaction est proportionnelle à la densité du combustible, la condition porte en réalité sur le produit de la densité par le temps de confinement. Si n désigne la densité, mesurée en nombre de noyaux de D ou T par cm^3, et si t désigne le temps de confinement en secondes, la condition s'écrit, pour la réaction (D,T):

$$nt \geqslant 10^{14}\ \mathrm{cm}^{-3}\ \mathrm{s}\ \text{(critère de Lawson)}$$

Les densités envisagées varient en pratique de 10^{14} à 10^{16} particules par cm^3 et les temps de confinement correspondants vont de 1 seconde à 1/100 de seconde.

Il faut maintenant situer les résultats des recherches par rapport à ce critère. Il est impossible de passer en revue les types très différents de dispositifs de confinement qui ont été expérimentés. Bornons nous à signaler que les meilleurs résultats ont été obtenus jusqu'à présent avec des dispositifs d'une famille bien particulière, originaire de l'Institut Kurtchatov de Moscou, qui porte le nom de "Tokamak". L'un des derniers nés de cette famille est l'appareil TFR du Centre d'Etudes Nucléaires de Fontenay-aux-Roses qui se trouve actuellement en tête par ses performances. Le plasma a la forme d'un anneau qui est plongé dans un champ magnétique et parcouru par un courant. L'intensité de ce courant est le paramètre le plus caractéristique des performances: elle a atteint récemment 300 kA, alors qu'elle ne dépassait pas 200 kA dans les autres appareils Tokamak. L'énergie moyenne des électrons est de 2 kilo-électron volts (keV) et celle des ions atteint 1 keV. Cette dernière énergie correspond à une température de 10 millions de degrés. La durée de la décharge est normalement d'une demi seconde, mais le temps de confinement de l'énergie, t, qui est la vraie grandeur à considérer dans le critère de Lawson, varie entre 10 et 20 ms, alors que la densité n est d'environ 5×10^{13} ions ou électrons par cm^3. Dans les meilleures conditions, le produit nt atteint presque $10^{12}\ cm^{-3}$ s, à comparer à 10^{14} pour satisfaire au critère de Lawson. Il reste donc à gagner un facteur 100, ce qui n'est pas effrayant: en effet, l'accroissement des dimensions géométriques peut facilement faire gagner un facteur 10. Le deuxième facteur 10 devra être gagné en augmentant la température et éventuellement en augmentant la densité.

Un projet de grand appareil du type Tokamak capable d'atteindre le critère de Lawson est actuellement en cours d'étude dans le cadre d'une collaboration entre les laboratoires européens. Il est probable qu'un tel appareil pourra être construit d'ici 1980, ce qui donne une idée du délai dans lequel le problème du confinement magnétique peut être finalement résolu.

Une fois franchie cette étape importante, il restera à réaliser la récupération de l'énergie et la régénération du tritium. Comme on l'a vu, l'essentiel de l'énergie est emporté par les neutrons qui s'échappent nécessairement du plasma thermonucléaire peu dense. Cette énergie apparaîtra sous forme thermique dans le milieu où les neutrons seront ralentis et absorbés. Par contre, l'énergie cinétique des particules alpha est dissipée dans le plasma et permet d'y maintenir la température convenable. Des études de principe ont déjà été faites et ont montré qu'un réacteur de ce type était concevable, y compris la régénération et même la surrégénération du tritium en absorbant les neutrons dans du lithium. Toutefois il est clair que les réacteurs thermonucléaires poseront des problèmes technologiques très difficiles.

IV. LA FUSION PAR LASER

Une voie de recherche tout à fait différente est celle des explosions comme nous l'avons vu au début. Il doit s'agir naturellement d'explosions suffisamment petites pour permettre une production d'énergie utilisable dans des conditions industrielles normales. C'est seulement récemment qu'une ouverture prometteuse est apparue dans cette voie grâce au développement des lasers de puissance et à des travaux théoriques faits principalement dans les laboratoires militaires. L'idée clé, déclassifiée depuis peu, est de réaliser une compression du combustible jusqu'à des densités très supérieures à la densité du solide, ce qui permet une combustion beaucoup plus rapide. Le principe est de mettre le mélange de deuterium–tritium sous la forme d'un petit glaçon sphérique et de l'irradier avec des faisceaux de lasers convergents disposés de façon à réaliser approximativement la symétrie sphérique. La surface du glaçon est alors brutalement vaporisée et même ionisée. Le plasma qui s'échappe dans toutes les directions produit un effet de recul, ou un effet de fusée convergent, qui entraîne une implosion de la partie centrale de la cible.

Le principe peut paraître simple, mais les ordres de grandeurs nécessaires pour réaliser la fusion sont impressionnants. Il faudrait atteindre, au centre du grain de mélange deuterium–tritium, une densité dix mille fois plus grande que celle du solide et en même temps des températures de millions de degrés. D'après des calculs très élaborés, ceci doit être possible si l'on peut disposer de lasers capables de fournir des impulsions de plusieurs kilo-Joules dans des temps de l'ordre de la nanoseconde. En fait, il faut aussi que l'impulsion fournie par le laser ait une forme bien particulière.

Sur le plan expérimental, les résultats les plus récents semblent vérifier le principe de la compression. Les informations disponibles sont malheureusement assez réduites du fait du caractère plus ou moins classifié de ces travaux. Les mieux connus sont ceux de l'équipe du Professeur Basov à l'Institut Lebedev de Moscou. Cette équipe est persuadée d'avoir atteint un facteur de compression de 30 environ dans une expérience comportant 9 faisceaux de laser convergents, mais sans pouvoir en apporter encore la preuve. Quoiqu'il en soit, on peut avoir confiance que la démonstration expérimentale de l'implosion et de la compression sera faite dans un avenir proche avec des valeurs de cet ordre pour le rapport de compression.

Par contre, il est beaucoup plus difficile de faire des prédictions sur la possibilité d'atteindre le but ultime, c'est-à-dire les conditions nécessaires à la fusion. Il subsiste encore quelques inconnues d'ordre physique, en particulier sur les processus d'absorption de la lumière incidente, mais le succès semble dépendre principalement du développement de la technique des lasers de puissance. Les différentes caractéristiques nécessaires, énergie, puissance, forme de l'impulsion, rendement énergétique, sont toutes à portée de la main lorsqu'il s'agit de les atteindre séparément avec des lasers différents, mais leur réalisation simultanée avec le même laser est certainement d'une difficulté considérable.

V. PERSPECTIVES DE L'ENERGIE THERMONUCLEAIRE

Il faut maintenant chercher à extrapoler la situation technique actuelle pour imaginer les perspectives offertes par la fusion thermonucléaire comme future source d'énergie industrielle.

Il est déjà clair que les unités de production d'énergie thermonucléaire auront des puissances très importantes, d'au moins plusieurs gigawatts thermiques. C'est l'ordre de grandeur auquel on arrive dans les études de principe qui ont été faites sur la production d'énergie par

la voie du confinement magnétique. Aucune étude analogue n'est encore disponible pour la fusion par laser. L'application à laquelle on pense est donc la production d'électricité dans des centrales de taille au moins égale aux plus grandes centrales actuelles.

Quel est maintenant le calendrier de l'effort de recherche et de développement qui pourrait conduire à de telles centrales? Il y a forcément une grande part de conjecture dans toute réponse à cette question. Mais on peut tout de même citer le calendrier proposé par l'AEC américain comme hypothèse de travail pour préparer un plan pluriannuel de recherches sur la fusion contrôlée. La première étape est la démonstration définitive du confinement magnétique dans les conditions nécessaires à la fusion: ceci devrait être réalisé vers 1980. Ensuite viendrait, dans les années 80, une installation capable de produire de l'énergie avec un mélange de deuterium et de tritium, sans régénération du tritium. Finalement la première centrale de démonstration, disons l'équivalent de la centrale Phoenix pour les neutrons rapides, pourrait fonctionner aux alentours de l'an 2000.

Une autre question importante vient également à l'esprit: celle des ressources en combustible. Dans le cas de la fusion deuterium-tritium, la limite est fixée par les ressources en lithium. Sans chercher à donner des chiffres précis, disons que le lithium disponible sur l'ensemble du globe sous forme de minerais riches permettrait d'assurer la production mondiale actuelle d'énergie électrique pendant plusieurs siècles. Une autre façon de répondre à la question est de faire une comparaison avec les réacteurs à neutrons rapides en profitant du fait que les disponibilités en uranium font l'objet de nombreuses études et publications. On peut admettre en effet que les ressources en lithium et en uranium sont d'importance comparable: le lithium est quatre fois plus abondant que l'uranium (en masse) dans la croûte terrestre. Or l'énergie produite dans un réacteur thermonucléaire pour un gramme de lithium consommé serait approximativement la même que dans un surrégénérateur pour un gramme d'uranium naturel consommé, soit de l'ordre de 1 MW $\times$ jour d'énergie thermique. On peut donc retenir que la réaction D,T offre une source d'énergie d'importance comparable à l'uranium utilisé dans les surrégénérateurs et on peut laisser aux spécialistes le soin de discuter quelles sont les teneurs de minerai acceptables.

L'utilisation de la réaction (D,D) offrirait évidemment des perspectives autrement plus vastes. En brûlant le deuterium contenu dans les océans, on pourrait faire face à la consommation mondiale actuelle d'énergie électrique, pendant des millions d'années. Malheureusement, il est encore impossible de dire si la production d'énergie par la réaction (D,D) sera un jour réalisée. Les conditions imposées au confinement magnétique pour son utilisation sont beaucoup plus sévères que celles que nous avons vues pour la réaction (D,T) et il faudra certainement attendre d'avoir une certaine expérience de la fusion contrôlée par réaction (D,T) avant de pouvoir conclure à la possibilité ou l'impossibilité d'utiliser la réaction (D,D).

Finalement, il faudrait pouvoir dire quelque chose sur les conséquences de la fusion contrôlée pour l'environnement. Mais les idées sur les réacteurs thermonucléaires sont évidemment trop schématiques et trop provisoires pour qu'on puisse vraiment traiter cette question. Mais des tentatives ont tout de même été faites pour aborder le sujet et on peut en retirer quelques remarques. La façon la plus simple de les présenter est de faire une comparaison avec les centrales nucléaires de fission. Ceci sans aucune intention de compétition et encore moins de polémique, la fusion contrôlée devant d'ailleurs, à mon avis, avoir pour l'énergie nucléaire de fission les égards qui sont dus à la génération précédente. En deux mots, dans la fusion, comme dans la fission, il y a des neutrons qui rendent actifs les matériaux de structures. Dans la fusion il y a le tritium, mais il n'y a pas les produits de

fission. Il n'y a donc pas de déchets radioactifs, autres que l'installation elle-même après sa fermeture, ou les pièces actives qui auront dû être remplacées en cours d'exploitation. La manipulation du tritium sans danger pour l'environnement est un problème technique qui demande beaucoup d'attention, mais qui est parfaitement soluble. Par contre, l'activation des matériaux de structure sera a priori plus importante dans une centrale thermonucléaire à deuterium–tritium que dans une centrale nucléaire à fission. Il faut noter aussi que le danger d'emballement de la réaction nucléaire n'existe pas dans le cas de la fusion.

En conclusion, on peut dire que la fusion thermonucléaire utilisant la réaction deuterium–tritium a de bonnes chances de se confirmer comme une source d'énergie capable de satisfaire la consommation mondiale à long terme, à l'échelle de plusieurs siècles. La possibilité d'utiliser la réaction deuterium–deuterium qui n'est pas encore démontrée, apporterait une solution pratiquement définitive à tous les besoins d'énergie imaginables de l'humanité.

SUMMARY

A brief review of the present status of research on controlled thermonuclear fusion is presented and the prospects of power production are indicated. The concept of thermonuclear fusion is recalled along the two lines of magnetic confinement and laser fusion. The goal of research on magnetic confinement is defined quantitatively with the Lawson criterion and the present achievements are described in the case of the Tokamak machines. The idea of laser fusion is briefly described. In the last part the various stages of a possible future development are outlined and the main problems raised by industrial power production are summarized.

DISCUSSION

LEWIS: Anyone wish to raise a question on this paper?

HUET: Je pense qu'on ne peut rien dire du prix de revient de l'énergie de fusion, mais je voudrais poser deux questions: Peut-on avoir un ordre de grandeur du budget de recherche actuel dans ce domaine et de ce que représenterait le programme en 3 points qui nous a été indiqué? Est-ce qu'un accroissement des crédits dans ce domaine permettrait de raccourcir les délais envisagés?

TROCHERIS: On peut en effet citer quelques chiffres pour situer l'ordre de grandeur de l'effort. J'ai parlé tout à l'heure de milliers de chercheurs. Du point de vue du budget l'effort total des pays de la communauté européenne en 1974 se monte tout compris à 60 millions d'unités de compte ou de dollars. Le budget correspondant des américains pour l'année fiscale 73–74 était à peu près de même ordre. Pour l'année 74–75 je crois qu'il atteindra 100 millions de dollars. Je pense que le niveau des dépenses à l'échelle d'une grande puissance comme les Etats-Unis ou l'Europe occidentale devra atteindre pour continuer ce programme peut-être le double du niveau actuel.

Maintenant il y a une question importante qui a déjà été posée? Est-ce qu'on irait plus vite avec beaucoup de moyens? La réponse est: non, en fait on n'irait pas beaucoup plus vite.

LAWAND: Vous avez fait référence, vous avez fait allusion à la quantité de D et T limitée par le lithium sur la terre et vous avez parlé de quelques siècles de pouvoir possible de fusion. Moi j'avais l'impression que c'était illimité. Ai-je tort?

TROCHERIS: Je renvoie la question au spécialiste. Le lithium n'est certainement pas aussi abondant que le deuterium. Moi j'ai simplement retenu que les ordres de grandeur étaient les mêmes que pour la fission par les réacteurs sur-régénérateurs où suivant la teneur du minerai qu'on accepte on peut aller assez loin ou très loin.

LEWIS: I think that Weinberg and Hammond at the last Geneva Conference in 1971 dealt with this question very satisfactorily and they said that the time would be indefinite. Let me say that my own phrase was "thousands of centuries".

ZRAKET: I just wanted to add a point about the question that came up on laser fusion. I'm not a specialist either, but the recent Cornel study, done under Dr. Hans Bethe for the AEC as part of Project Independence, announced that they think they could now plan to build 100 MWe electrical demonstration plant by 1990 at an accumulated cost of about \$4 billion of research and development between now and then because of this very promising development of cutting the power needed by a factor of up to 10^5 with the increased density achievable by multiple beams.

TROCHERIS: I think that this is highly speculative. Obviously you can't prevent people from imagining reactors with such concepts. But even the way you would produce and extract the energy is not at all simple. You don't even know what the size of the explosion would be. I mean there is a large difference between the state of the art, or rather the state of paper work on reactors in both cases: it is much more advanced in the case of magnetic confinement than in the case of laser fusion.

LEWIS: Let me add a word here. I feel it is very wrong for these international conferences to go on talking so airily when in fact the specific technical problem is known. The specific technical problem is that light only travels in straight lines. If the light is going to hit the target and produce 14 MeV neutrons, some 14 MeV neutrons will come back along the same track. There is nothing to stop them. The damage done by the 14 MeV neutrons from the explosion on the laser optics, the last laser optic, is always very much greater than the value of the energy released. That is the problem. There is some advantage for a liquid metal mirror, but I think it is rather more than a simple technical problem. Let us say that technical problems are thick around this subject. 14 MeV neutrons are not the best way of taking energy. They are some of the most damaging entities that we know. Many of these designs of reactors which people have enjoyed producing, other people have shown would last for only a few seconds for their life. That's that, and then you rebuild it. This is the type of problem that one is really dealing with. We have not got a Periodic Table that is infinitely extensible. We have only the 92 elements and certain particular isotopes. It is extremely difficult to see how these things are ever going to make a practical scheme for the scale of operations and the time of operation needed at a cost that would make it competitive with other very generous sources that we already have. It's a beautiful dream, but it's still in that land of fantasy. I'd like to throw the whole afternoon's session open to questions.

DOSTROVSKY: These are not so much questions as comments or observations of a few points which may not come up again in our sessions. I refer to the solar energy paper and to the hydrogen paper. First, with respect to solar energy, I think it is very important to approach this source with a really careful appreciation of its potentialities and its problems and to avoid two extreme conclusions, both of which would be unwarranted and bad. One is the super optimistic one which says that solar energy is going to solve all our energy problems after the year 2000, and the other one—the pessimistic view—that it is not going to do this and therefore we should drop the whole subject and not pursue it any more. There is a tendency towards this kind of polarization. The proper appreciation of solar energy is that it is a very valuable source, an important source for a particular situation. These particular situations may not amount to 100% of our energy needs; they may amount to only 10 or 15% or even 5%, but these situations may be very important in improving the quality of life in certain circumstances. So that the actual value is measured not so much in the per cent of the total energy which solar energy provides us but in the contribution it can make to the quality of life. In terms of such banal things as space heating, space cooling, provision of hot water supply, provision of small amounts of electricity (and not necessarily thousands of megawatts), solar energy is important.

These may not sound terribly exciting compared to the dreams of large scale fusion or fission, but nevertheless I think their importance is very great to the quality of life, and furthermore these applications of solar energy are feasible on the time scale we are talking about. If we are talking about 25 or 30 years, these are entirely feasible projects. The plea that I am making is that we should really keep a sound perspective on what is happening and not go off on tangents of the two extremes. We should keep plugging ahead at solar energy, even if it does not provide all our needs but only some of our needs, because it will serve the people who need it most. So that is the plea I'm making for solar energy—that we don't jump to these two extreme conclusions. On the other one, I'm afraid I'm going to have to take a somewhat pessimistic point of view on the hydrogen question. There is no doubt about the usefulness of hydrogen, and all the positive qualities have been stated very clearly and they are all correct. Therefore the tendency is to talk about the hydrogen economy in the year 2000. But as I think we heard in the talk by Caprioglio, we have no cheap way of making hydrogen. And there is none in sight at the moment. I personally, and some of my colleagues, have gone very carefully through all the chemical cycles proposed and found them not at all promising. First of all all the chemical cycles are essentially Carno machines: they really do nothing more than move heat between two temperatures—high and low—and you can't beat thermodynamics. Those of you who know about the chemical problems realize that you have to go through several cycles to get a closed operation. The more of these you do, the further away you get from the optimum kind of efficiency. By the time you've done that, you're really dropping again to pretty inefficient thermodynamics. Even on the basis of pure thermodynamics, you're taking a beating. On top of that the chemical engineering problem is not at all trivial. These cycles involve some of the most unpleasant things one can deal with, like halogens and things of that sort at high temperatures. So the whole thing does not really make very much sense. If you already have a reactor producing 1000°C heat, you can make a pretty efficient cycle without violating any thermodynamics. So my feeling is that the way we can beat this problem is with electrolysis. If I had to put my money on one direction or another, I'd say keep out of the chemical cycles and put all you can on making an 80 or 90% efficient electrolysis cell and then with a high temperature reactor, giving you about 50% thermodynamic efficiency or more; you would be much further ahead than if you were working with chemical cycles.

LEWIS: Thank you. May I say I think you would be ahead. But why be so greedy? The energy that we're talking about is very cheap. The power that we're talking about is very cheap. There are prospects of using hydrogen, so certainly we are involving electrolysis, and it isn't 90% efficient, if by which you mean that in relation to chemical free energies we're releasing it with less than 90% efficiency. But this doesn't mean that it's impractical at all. As far as the chemical cycles are concerned, I agree. I've been horrified by some of the suggestions. But there is still a lot of work going on. And one knows that a great deal of this is not being exposed to public view. If you read the annual lecture to the Electrochemical Society given this year and at the same time read the information available in *Chemical and Engineering News*, more or less published at the same time, you'll be very well aware that the lecturer to the Electrochemical Society withheld a lot of information. We must presume that this is going on still. A lot of this information is withheld for industrial secrecy reasons. So I wouldn't like to say that all these things are out.

CAPRIOGLIO: I could add one consideration to what you have just said. I think this consideration is rather convincing. Let me make one example. You have a nuclear power reactor which is the same in both cases, producing heat at a suitable temperature, whatever it is. With one of them you make electricity and electrolysis and you make hydrogen. With the other you make a chemical cycle and you make hydrogen. Let us assume that you have the same efficiencies on both sides. This is a very fair assumption if you think of the need of going through three steps in the case of electrolysis because you have to make the electricity, then rectify it, then electrolize it. The comparison is: What is the capital cost in the first case and what is the capital cost in the second? In the first case you have turbo-machinery plus the alternator, plus the rectifier, plus the electrolizer. This is a lot of money. It is known that for the electricity portion, if you start from steam

and you go to electricity, you spend a capital cost something like 40% of the total power station. Then the rectifier, then the electrolytic plant . . . if you want to arrive at very high efficiencies, inevitably it's going to be expensive. Because you use special materials, because you use catalysts, because you use very fine working. methods. Now for the same price, I cannot believe that one cannot make a chemical plant, however complicated it may be, provided (and here I would agree with what you said) one is not talking about too many reactions. To give an example: the cycle that is now being looked at as the most promising in ISPRA has three reactions: it involves only iron and chloride, therefore materials that are well known in the chemical industry. I believe that it is perfectly conceivable that one can make hydrogen at a lower cost than through the electrolysis route. I would even say that it is certain. The real problem is how much is it worth spending to make hydrogen by using nuclear energy in comparison with the money that is being spent, let's say in the energy field, in the field of the primary energy sources. To my mind, one is spending altogether too much money in developing all kinds of alternatives in primary energy sources and too little money on how to use these primary energy sources in a reasonable and economic way—acceptable to the environment, etc.—in order to satisfy the whole lot of needs that a complex civilization requires. Practically nothing is being done in this second field. We go on burning petrol in our cars, burning kerosene in our airplanes, making coke for making steel, and so on and so forth . . . we talk about breeding nuclear energy and therefore solving mankind's problems as far as raw materials are concerned . . . but how are we going to use this energy for running an airplane? Who is doing anything to do that? This is the real key to my mind. It can be hydrogen or something else, but the problem of the vector to transform the primary energy source into something that is really usable in an economic way is the key problem.

LEWIS: May I bring you back to your own words, though: you said that the cost of plants and so on was very easily taken by the cost of the energy that was involved. I'd like to put this in focus. The turbo-alternator, that is to say the converter from steam to electricity, including the auxiliaries, in 1972 dollars was about $35 per kWe. That is quite a low figure to beat by other methods. This is arrived at, of course, by practice. These large turbo-alternators are quite established—the cost per kilowatt is not reduced at all above 600 MW output. We have to keep these figures in mind as the challenge—that doesn't mean that there can be no competition—in fact we're hoping that even producing electricity from steam will one day cost less than $35 per kW. But there we are at the moment. In changing these processes, you've gone to processes that are indeed much cheaper in equipment than the original.

CAPRIOGLIO: Just one word on this. You may remember that in my too short presentation I hinted at the fact that I was a great believer of hybrid systems. Why? Because that would allow you to have extremely simple chemical cycles using just one chemical reaction that would use thermal heat at the best temperature, making electricity with the rest of it or by any other means, and using the electrical energy in order to do the difficult step, which in general is to make hydrogen. That appeals to me because hydrogen is made in a very efficient way by electrolysis. By the way, as a bonus, one can compress hydrogen electrolytically in a very cheap way, practically in a reversible way. It costs very little to compress hydrogen electrolytically, and therefore this is a very big incentive in making hydrogen from an electrolytic step. So if you combine all the advantages of both systems—and this seems possible—one can arrive at something that may be very, very cheap and therefore likely to be able to conquer a large fraction of the energy market. So I'm not ruling out electrolysis at all. On the contrary, I think that all progress that can be made, in particular on the hydrogen electrode in terms of power density, is going to be very useful. I hope I have given a balanced view on this.

LEWIS: We have two more questions waiting on this.

LEHMANN: La réunion de cette journée a été consacrée à l'étude des ressources énergétiques à long terme mais dans l'examen des besoins énergétiques qui ont été notamment présentés d'une façon si intéressante par M. Zraket il m'a semblé que l'on considérait presque uniquement les besoins aujourd'hui classiques en énergie tels que ceux relatifs au chauffage, au transport et aux besoins industriels actuels. Dans une session voisine on étudie les ressources minérales à long terme et il me semble que l'on ne peut pas séparer l'un de l'autre ces deux problèmes. Il me semble qu'il ne peut pas exister d'épuisement des ressources minérales si l'on dispose de suffisamment d'énergie, car la masse de nos ressources minérales est considérable, c'est la masse globale de la terre. Qui aurait pensé il y a 75 ans que l'on produirait de l'aluminium en immense quantité avec des cailloux alors tout à fait inutiles, plus de grandes quantités d'ènergie. La question que je désirais poser est la suivante: ne faut-il pas dès aujourd'hui examiner quels pourraient être les besoins supplémentaires et nouveaux d'énergie qui permettraient de répondre à certaines des questions posées par l'épuisement—par exemple des matériaux à base de carbone? Si l'épuisement des ressources pétrolières pose des problèmes sur la fabrication des plastiques ils peuvent être remplacès par de l'énergie et de la craie. Il y a peu d'années encore les plastiques se faisaient à partir de la craie et non pas à partir du pétrole. Je vous demande donc d'examiner si d'autres chapitres ne doivent pas être ajoutés aujourd'hui, ceux qui concerneront des besoins d'énergie destinée à la création de nouvelles ressources minérales au fur et à mesure que s'épuiseront celles que nous utilisons aujourd'hui.

LEWIS: Thank you. I'll ask Dr. Zraket to reply to part of that, but before doing that I'd like to throw in another figure and that is if we have exhausted all of our coal and we still want hydrocarbons for flying our

airplanes, the extra cost of taking it out of limestone is $3 to $5 a barrel. It isn't something astronomical even when you've finished using coal.

ZRAKET: I agree with the gentleman's comment that energy is essential to the continued supply of other mineral resources. As I said earlier, I don't think that "nature" is the problem with respect to mineral resources; it is our ability to extract and recycle the necessary materials that we need. Having said that, I intimated that with respect to the year 2000 problem, and beyond, increasing amounts of energy were going to be needed for at least primary metal processing and that is why I postulated that we were going to need larger and larger industrial port complexes to juxtaposition energy sources and primary metals and other minerals. I don't know of any conclusive studies on the issue you have raised, namely is it worthwhile expending our fossil fuel resources because they're such a crucial feedstock for things like the petrochemical industry and possibly food generation. I don't know the answer to that. Some of my friends tell me that we're still better off using the old economic law, that is using what's best now and worrying about the future later. Other people, say, save the fossil fuels.

BLACKSHEAR: I don't know how familiar you all are with US sources. A team at NACA Lewis laboratory 20 years ago did some extensive experiments on the use of hydrogen for jet engine propulsion. The scheme was diverted for a number of reasons, one of which was when the experimental plane was going to make its maiden voyage it had to sit a little extra long on the runway and there was such a thick layer of ice on the outside of the skin that the fuel tanks became encrusted with enough ice that it was unable to take off. Recent experiments in burning hydrogen in internal combustion engines suggest that really remarkable performance in the spark ignition piston engine can be attained by virtue of the fact that hydrogen has such a wide range of flammability. Successful non-knocking combusting can be attained at very lean fuel-air ratios. Finally, just to respond to the last remark, Alvin Weinberg and his team tried to estimate what the replacement of the various resources would be with energy, and if the chairman permits, I'd like to read some of them. Bearing in mind that the United States uses approximately 10 kWt per capita the replacement for our present level of consumption of such things as steel, aluminum, and magnesium, things that are in great abundance in the earth's crust, which would require us to go to lower grade ores, would require one-tenth of a kilowatt per person. In other words, a 1% increase in the total energy consumption to go to lower grade ores. Those things that are relatively scarce, that would require recovery and recycling—copper, lead, tin, zinc, gold, silver, etc.—would cause an increase of about 2 kW per person. Replacing hydrocarbons for convenience fuel with electrolytic hydrogen would require an additional 2.5 kW per person. The overall budget increase by the Weinberg and associates estimates is 6 kW per person. In other words, less than doubling of the present US per capita energy use, would allow a resource-depleted world to maintain present US consumption rates for the indefinite future.

LEARDINI: I'm coming back. Mr. Chairman, if you allow me, to some questions regarding the pollution in the environment in the exploitation of the geothermal energy. The items should be discussed tomorrow morning apparently and perhaps I'm anticipating some data, but since I'm not able to attend the meeting and to listen to Mr. Rex's report, perhaps I may make my comments now. I should say that the environmental impact of geothermal energy can be classified under a few typical aspects. The first one is the thermal rejection and evidently it depends upon the temperature and pressure of the steam. The thermal rejection of a natural steam power plant (or a geothermal steam power plant) is nearly the double of the one you have by actual fuel-fired power plants and, say, 1.5 times as much the one of the nuclear power plant. So it is a problem which cannot be avoided because it is a thermodynamical problem. We usually have low temperature natural steam and there is no great hope to increase it. Second is the gas rejection. The fluid always carries gases in minor or bigger quantities. In some cases the initial content of a gas may be as high as 80–90%. (We discovered just a few days ago a well producing 90% of CO_2.) The content of steam is increasing and in a time of two years the Co_2 quantity will drop down, we hope, to 6–8%. This is the usual way. The gases which are carried by the steam are usually not very noxious. The greatest quality is CO_2, and then we have a minor quantity of hydrogen sulfide, methane, and other gases. We don't think the discharge of those gases is a problem. We usually take precautions. A medium-sized stack, let's say 150 or 200 ft high, allows for an efficient disposal. The dilution in the atmosphere is such that even in the nearest surrounding we do not exceed the most stringent regulations as regarding these gases. Another type of pollution is given by the solids which are carried out either by steam or by the water which is quite frequently accompanying the steam. The salts contained in the water may be higher than those admitted for water discharges. For instance we have discovered a few weeks ago a well which is producing very hot water and steam, but the water contains 6 part in a million of arsenic compounds. This is more than 10 times as much as it would be allowed to discharge. There are two basic solutions: one (which we already do) is the re-injection within some well near the steam well, which is nearby, after checking that the re-injection well does not end into a water table, utilized it to get out drinking water. The second way is to extract the salts and store them. For instance, the extraction may happen by means of ion exchangers. The waters deriving from the regeneration of the ion exchangers are thereafter concentrated. We tried to figure out the cost. The first type of disposal, which is the re-injection, is the most economical one. There is still a major question which has not yet been solved. It has been encountered in some geothermal fields in the southern part of the United States,

which are yielding very high temperature salt brines, containing as much as 25% in weight of salts. The main component is given by natrium chloride, and since this cannot be utilized, there is a problem in storing it. If some kind of heat exchangers could be provided to utilize the heat content of the very high temperature brines (which may reach 260°C) it is hoped that some of the components of the brine can be recovered because the brine carries such valuable elements like uranium, gold, mercury, and so on. It could be that the heat extracted from the brines could be used to process the most valuable part of the salts.

LEWIS: Thank you very much, Dr. Leardini, for these contributions which, as you say, take us towards tomorrow morning's discussion. I hope we will see you here again in this conference later on. Perhaps when we're summarizing these things.

KELLOGG: There is one juxtaposition of ideas which may already have been made and perhaps I missed it. I have heard that hydrogen could be cheaper to transport through pipes than electricity in terms of its equivalent energy content. I think this point was made here several times. I've also heard—and I haven't heard this mentioned here—the idea of cryogenic superconducting distribution lines for electricity. Have studies been made to see if a *combination* of a cryogenic electrical distribution line with pipes carrying liquid hydrogen makes any sense?

CAPRIOGLIO: Yes, indeed, it makes sense. Studies are being carried out, essentially in the United States, but I understand in Europe as well in a few places, to study the possibility of transporting at the same time liquid hydrogen and electricity in a cryogenic way. Here I would like to make a difference between a cryogenic line and a superconducting line. If one has a superconducting line available, then of course the whole problem of large quantities of energy in the form of electricity would largely be solved. It depends, of course, on the cost of the operation. But one would not necessarily produce the hydrogen at the same place and transport it. So it may very well be that one would simply cool down the superconducting line and alongside transport hydrogen in a gaseous form because it is much cheaper to transport hydrogen in a gaseous form than in a liquid form.

LAWAND: . . . method of looking into this storage problem. I'd like to know if anyone else—perhaps I've not made myself too clear, but is it perhaps not possible that in 100 years' time the pattern of distribution of our energy will be so different and this will dictate the technological considerations that we will have to be debating?

LEWIS: I agree there may be a difference. But I think it would take too long to peer that far in the future.

DESTIVAL: A la fin de ces débats, je reste sur une interrogation. Nous avons parlé de beaucoup de projets, d'énergies nouvelles solaire, géothermie, hydrogène. Il y en a d'autres dont on n'a pas parlé, peut-être plus classiques, l'exploitation sous quelques centaines de mètres, la gazéification du charbon, l'exploitation des sables, des schistes, par extraction, par explosion nucléaire, l'activation des gisements, etc. Il y a actuellement une prolifération d'idées que l'on constate dans tous les pays. Et je me pose la question—est-ce que tout cela est nécessaire, tour de suite, est-ce que peut-être même, en allant dans toutes ces directions, on va dans celle qui convient, est-ce qu'on n'oublie pas quelque chose qui est plus important? Cela mène à une seconde question, qui était celle que je traitais ce matin: de quelle quantité d'énergie l'humanité aura-t-elle besoin dans trente ans, dans cinquante ans? Quand j'entendais M. Zraket dire: "Eh bien nous avons fait un scénario où l'homme consommera 50 kilowatts— l'humain moyen, ce qui veut dire qu'il y en aura qui consommeront sans doute 2 ou 300", je m'interroge: mais quel sera son mode de vie, comment fera-t-il pour consommer tout cela? C'est un peu comme si on nous disait dans cinquante ans l'homme consommera cinquante fois plus de nourriture qu'aujourd'hui. Il y a tout un travail d'investigation à faire et des questions aussi fondamentales, devraint être à la base de la réflexion pour déterminer, de préférence au plan mondial, quelles sont les actions importantes en matière de recherche et de dévelopement à long terme qu'il faut entreprendre.

LEARDINI: May I come back to the question of Mr. Kellogg on the merits of transmitting cryogenic fluids like liquid nitrogen or liquid hydrogen or liquid helium through a superconducting device or a cryoresistive device. We figured out the operation cost of a cryoresistive cable cooled by liquid nitrogen, which was at the same time used as a carrier of liquid nitrogen for freezing purposes, and we found that there was no economic incentive in combining cable cooling and nitrogen transmission even if the liquid nitrogen was very inexpensive at the source, since it derived from gasification of liquid natural gas. So I don't think there will be any great incentive in making that by hydrogen. Only a further progress could change the picture. The progress to be achieved is to obtain superconducting materials at the temperature of evaporation of hydrogen. Although some preliminary favorable results have been obtained we are still very far away from the time by which a reliable production of superconductors at liquid hydrogen temperature may be obtained. Until then, we have to rely on helium to achieve superconductivity in existing S_n, N_b, etc., alloys.

ZRAKET: I wanted to make a brief comment on the point Mr. Destival raised. As he noted in the two scenarios I presented there was a 50 kW per capita use in the year 2100 and in the other there was a 20 kW per capita use in the year 2100. They were presented for purposes of illustrating energy needs. But I think it is a good question to raise in any look at potential energy sources to ask when can we reach zero energy growth per capita or somewhere near zero energy growth per capita, at the same time we are continuing to

improve the economic and environment system. Some people in the United States claim we can do it in 10 years, I don't believe that. But it might be possible to do it in 50–100 years.

RANDERS: It has struck me in these discussions about the future energy situation in the world that some people seem to feel that if we do not succeed with fighting pollution, extracting geothermal energy or whatever it is, we are heading towards some kind of catastrophe where the whole society is destroyed in some strange, mysterious way. This is, of course, not the case. There is always some way to survive. To produce enough energy we always have the possibility of covering the whole earth with solar cells and live in the basement underneath. This, theoretically, is possible. Energy from the sun certainly is sufficient if you are willing to sacrifice the surface of the earth. This may happen in the long run, because human beings, if they had a choice between walking on foot to their work in the morning or destroying the surface of the earth, would choose to destroy the surface of the earth. I think it's likely that in the very end we will have nothing else but solar energy. Even with fusion we will run out of fuel (deuterium) after a certain period. How would the world look if we have 100 billion people with only solar energy? Is there any way we could manage this so we could feed ourselves—at least theoretically? What I'm really trying to point out is that we are not heading towards a sudden catastrophe, but we're heading for rather unpleasant choices if we increase the number of people without thinking about future energy. I'm sure we will always manage to get by, somehow, but obviously the kind of life we shall then live on the planet may become very unpleasant. Of course we are adaptable. Maybe our descendants will think it is marvellous to live in the basement with a roof of solar cells above them. If so, we need not worry as much as we do.

LEWIS: I think we're trespassing on tomorrow's land. I'll give you a much more cheerful picture tomorrow afternoon. I see signs that people are getting a little weary so I would like to adjourn this meeting. Thank you very much for your participation. It has been very keen. Again, thank you very much to the translators. I have been listening with one ear to one language and with the other to another for most of the afternoon and it was going along extremely well. In fact I don't know how some of them manage it—I followed one better in the French after it was translated!

Chapter III

IMPACT OF ENERGETIC SOLUTIONS ON NATURE

Président: T. BEN MENA

CONTENTS

LONG RANGE INFLUENCES OF MANKIND ON THE CLIMATE

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INTRODUCTION: THE REALITY OF CLIMATE CHANGE

Climate change is an aspect of our environment that we must learn to live with though we often try to ignore it. Usually the changes are so gradual that we hardly sense them in the course of a lifetime, or if we do sense them we look at them as more or less random fluctuations around a stable average condition. There is something in our makeup that leads us to reject the idea that the present climate of our planet is not constant, not a thing that we can count on "forever".

Of course, we know from the geological evidence written on the face of the land, in layers of sediment in the deep sea, in the patterns of coal and fossil deposits, and so forth, that the earth's climate has in fact changed quite drastically in the past. We live now in a period when both poles are perpetually frozen over, but it was not always so. In fact, the present period of polar glaciation represents a condition that has existed for only 10–15% of the time, as seen on a scale of a few hundred million years (SMIC, 1971).

If we look at the shorter record of the past million years or less, a record that has now been deciphered in some detail from studies of sea-bottom cores gathered in many parts of the world, it is evident that we live in an unusual climate as seen on that time scale also. During the Quaternary, as this recent period is called, great ice ages have alternated about every 100 000 years with relatively brief periods of warmth, known as "interglacials", and we have now been in an interglacial for over 10 000 years. This has led to some speculation as to whether we are now due for another ice age, based simply on the rhythm of the fluctuations of the past (Mitchell, 1972; Emiliani, 1972; Kukla and Mathews, 1972).

The history of primitive man spans many transitions between ice ages and interglacials, and he has obviously survived these fluctuations by adapting to the changing environment and by migration. We do not know what struggles these ancient ancestors faced as the permanent ice and snow periodically spread over the northern parts of their continents, but we can guess that there was great hardship for those in the marginal areas of the earth—as is still the case.

The written history of mankind covers only the last 5000 years (or less), a period entirely within the present warm interglacial. Yet the relatively small fluctuations that have occurred in the climate during recorded history have also caused great hardship and forced major

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adaptations of entire peoples. Surely many of the migrations and invasions of tribes in Europe and Asia were triggered by such changes as marginal areas became uninhabitable. Even as recently as AD 1400 the cooling trend in the North Atlantic caused the Norse settlements in Greenland to be cut off from their homeland, and these colonies perished for reasons that we can only guess (Laduric, 1967).

In short, the planet earth has managed through the eons since its formation to maintain an environment of air, water, and land that has been able to support life, and that suggests that there is a remarkable inherent stability in the system that keeps the earth from straying too far and becoming like our inhospitable sister planets, Venus and Mars. Yet the fluctuations that have occurred are very real, and they are highly significant to all forms of life—including mankind.

It is in this perspective that we must view our future existence, and the kinds of adaptations that will be forced on us by climate changes.

SOME SOCIAL IMPACTS OF CLIMATE CHANGE

It is the ability to grow or hunt down enough food *locally* that limits the size of a primitive population, but in the world today this is generally no longer true. Most countries are dependent on exporting or importing food, especially the more advanced nations, and a growing interdependence among all societies now exists. If a country cannot raise enough food within its own borders it must import the difference, and its ability to do so depends on its complex balance of trade.

Looking at the world food situation as it exists in AD 1974 there are some new realities that must be recognized:

- The world population of some 3.9 billion people is still growing at a rate of slightly over 2% per year, which corresponds to a doubling time of about 35 years. The rate of growth in the less developed world is more than twice that in the developed countries.
- We are now consuming the food we produce as fast as we are producing it, and it is estimated that there exists no more than a one month reserve of food in the exporting countries, on the average, to feed the rest of the world (Mayer, 1974; Schneider, 1974).
- Food production is mainly in a few "breadbasket" areas, notably the United States and Canada. (The United States with about 6% of the world's population has 9% of the land that is under cultivation.) The area of land under cultivation has not been increasing as fast as the world population, but the rate of food production has almost kept pace due to improved crop yields (SCEP, 1970).
- The improved yields associated with the "green revolution" have been due to the introduction of more productive crop strains and use of more fertilizer and insecticides. Thus, the energy required to raise the necessary food has been rising, another factor that favors the developed countries and works to the disadvantage of the less developed countries (SCEP, 1970).
- The oceans will remain a large resource of food, but there seems little chance of increasing the productivity of the oceans by any large factor. Already some fishing grounds are apparently being overfished, such as the Grand Banks of the North Atlantic and perhaps the anchovy schools off the coast of Peru (the latter constituting about 17% of all the fish caught in 1970) (Mayer, 1974).
- A change of climate resulting in a decrease of food production anywhere in the world

now has global consequences, as evidenced by the international repercussions of the crop failures in the Soviet Union in the spring and summer of 1972 (Mayer, 1974), and the current tragic situation in the Sahel of Central Africa (Bryson, 1973).

It is this last point that must be emphasized in the context of this report. There will be crop failures again in parts of the world, and we are poorly prepared to cope with the consequences. As the total population grows and the margin between plenty and famine shrinks, *any* climate change will probably work to the disadvantage of this interdependent world society in which we live. The poorer and less developed countries will be hit the hardest.

WHICH WAY WILL OUR CLIMATE GO?

There have recently been a variety of speculations in the public press concerning the future course that our climate may take. They usually start by noting the fact that we have just passed through a highly non-typical period in the last few decades as shown in Fig. 1, taken from Mitchell (1974). The temperature maximum that occurred around 1945 seems to have

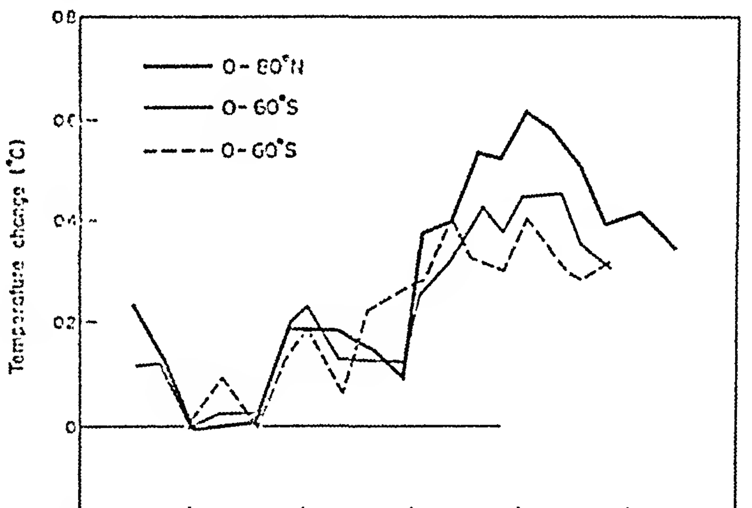

Fig. 1. Average temperatures for three latitude ranges relative to AD 1880. (After Mitchell, 1974; extension of curve for 0-80°N based on unpublished thesis by C. H. Reitan.)

been unequaled at any time in the past 1000 years, as shown in Fig. 2. It is therefore tempting to conclude that the world is sliding back toward colder conditions, similar to those that existed in the early part of the nineteenth century and before.

Of course, it would be naïve to base a prediction on a current trend without some reason for believing that the trend would continue. Bryson (1972, 1974) and Budyko (1973) believe that the present downward trend is due to mankind's production of particles (aerosols) from industry, transportation, slash-and-burn agricultural practices, overgrazing of marginal lands, expansion of ploughed land, and so forth, and the theoretical works of Rasool and Schneider (1971) and Yamamoto and Tanaka (1972) have been cited to show that a uniform increase in worldwide aerosol content should cause a cooling. The reason for this conclusion is that, if the lowlevel aerosols do not absorb too much sunlight but scatter it back to space, then the solar radiation available to heat the lower atmosphere and the earth's

surface will be decreased by an increase in aerosols. The average reflectivity of the surface was taken to be that of the ocean, which covers three quarters of the globe.

While this explanation seems reasonable at first and is hard to dispute, there are some serious doubts about it being the entire story (Mitchell, 1974; Kellogg and Schneider, 1974). Some of these doubts stem from observations that the aerosol content has in fact not been on the increase in many non-industrial areas in the past decade or so (Machta, 1972; EPA, 1973), and that the regions where aerosols have increased in this century are limited to the industrial areas and the oceans immmediately downwind of them (Machta, 1972; Cobb, 1973). Furthermore, theoretical calculations generally indicate that over land, where most manmade aerosols originate and remain until they are removed by rainout and wash-out, the relatively high reflectivity of the surface leads to a warming due to increased aerosol content rather than a cooling, as may occur over a darker ocean surface (SMIC, 1971; Schneider and Kellogg, 1973; Braslau and Dave, 1973). These do not by any means

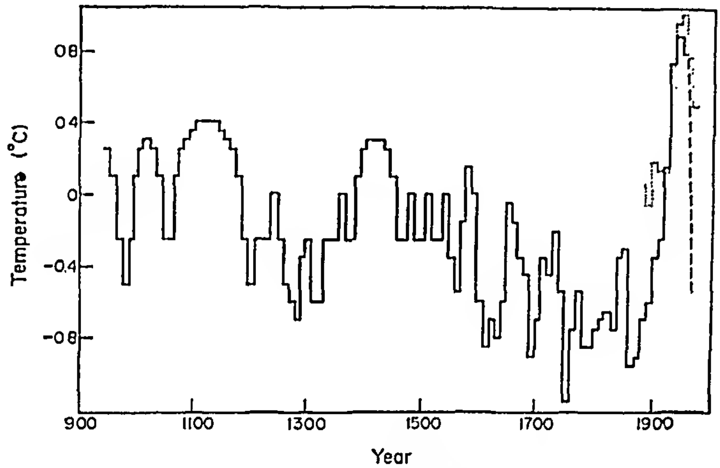

Fig. 2. Mean annual temperature in Iceland over the past 1000 years as drawn by Bryson (1973), based on data gathered by P. Bergthorsson. The heavy line indicates the temperature change of the last decade, and the dotted line the average Northern Hemisphere temperatures shown in Fig. 1 (with an uncertain location vertically).

prove that the manmade aerosol explanation for the present cooling trend is completely wrong, but that we should not stop looking for other and perhaps better explanations.

An important fact to keep in mind is that climate change has occurred many times in the past, before man appeared on the scene and became a new factor in the equation that governs the balance of the climate system. Thus, we should not be too surprised that a change is occurring and rush to find an anthropomorphic reason.

Looking at the future, it seems much more likely that the net effect of human activities will not be a cooling but will be a warming. The reason for this belief is as follows: the climate is determined, as we have said, by an overall balance between the solar energy applied to the atmosphere–ocean–ice–land system and the energy radiated back to space as infrared radiation. Anything we do to change this balance will change the climate. We are doing two things on a massive scale now, and the scale is steadily increasing—adding carbon dioxide to the atmosphere by burning the fossil carbon locked in the earth in the form of coal, petroleum, and natural gas, and also adding heat directly by our insatiable

demand for energy. Both of these cause the temperature of the climate system to rise, as we will demonstrate.

Carbon dioxide is a chemically very stable gas that is only destroyed when it diffuses into the upper stratosphere, and this removal process is extremely slow. However, when additional carbon dioxide is added to the atmosphere by burning fossil fuels, some of this additional amount is taken up by the ocean (is dissolved in the upper layers) and some is taken up by plants (mostly the forests of the world) and incorporated in the total "biomass". In the year 1950 some 6.4×10^9 tons (metric) were added, in 1970 this had risen to about 15×10^9 tons, and it is estimated conservatively that by 1990 the annual addition will be about 50×10^9 tons (SCEP, 1970).

Several attempts have been made to estimate the future amounts of carbon dioxide that will be in the atmosphere in the future, assuming a more or less exponential increase in the rate of release and taking into account the fraction that will be dissolved in the oceans and the fraction taken up by the biomass. There is a fair agreement between two recently published model calculations out to the year 2000 (Machta, 1973; Bacastow and Keeling, 1973), who predict that the concentration will rise from the 1971 value of 322 to 324 parts per million (ppm) by volume (SMIC, 1971; Ekdahl and Keeling, 1973) to 390 or 400 ppm by the year 2000. Bacastow and Keeling (1973) extend their calculations to AD 2040, and estimate the carbon dioxide content then to be between 710 and 900 ppm, the difference being due to uncertainties about the ocean and biomass fractions. (For example, will the forests be allowed to grow or will they be cut down?) Of course, there is also considerable uncertainty about the future rate of consumption of fossil fuels, and the above prediction is based on a continuing increase in the consumption at a rate of 4% per year. (The current annual growth rate of worldwide energy production, according to United Nations data, is 5.7% per year (SMIC, 1971).) There is probably enough coal in the world to sustain such a large consumption for at least the next 100 years (Hubbert, 1971), but hopefully alternative sources of power such as nuclear, thermonuclear, solar, etc., will begin to take over before then.

Now we turn to the climatic effects of such an increase in carbon dioxide. This gas is virtually transparent to solar radiation, but it has several strong absorption bands in the infrared part of the spectrum. Its ability to absorb some of the infrared radiation from the earth's surface and to reradiate it downwards means than an addition of carbon dioxide acts as a kind of radiative blanket and raises the surface temperature. This phenomenon has often been called "the greenhouse effect" (Schneider and Kellogg, 1973).

Theoretical calculations by Manabe and Wetherald (1967) estimate the effect of increasing the carbon dioxide content, and the average global temperature rise turns out to be roughly proportional to the logarithm of the average carbon dioxide content, as shown in Fig. 3. Thus, the increase by the year AD 2000 will produce an average temperature rise of 0.5°C, and the effect by AD 2040 may be 2.5°C or more. These are averages for the globe, and even the smaller figure is comparable to any of the global rates of change experienced in the past century (see Fig. 1). The rise by AD 2040, if it occurs, will be very pronounced indeed. Furthermore, we know that the high latitudes are much more susceptible to climate change, and it is likely that the high latitude temperature changes will be larger than the global average changes by a factor ranging from 1.3 to 3.0 (Kellogg, 1974; Kellogg and Schneider, 1974), and the equatorial changes will be correspondingly smaller. We will return to this latitudinal dependence later.

We might rest our case in favor of a future climatic warming at this point, since it must

already seem rather convincing. However, let us briefly consider what the *direct* heating from all our energy consumption will be in the years ahead. To begin with, here are some pertinent facts and figures. In AD 1970 the worldwide production of thermal energy was about 8×10^{12} W (or 8×10^{3} GW, a more convenient unit) (SCEP, 1970, which was based on United Nations data). Note that this is the heat released by all worldwide activities involving energy—heating, manufacturing, transportation, food production, etc.—and is considerably more than the productive energy that turns our wheels. All the energy we produce and use ends up as heat sooner or later.

This can be compared with the total amount of solar energy absorbed at the earth's surface, which is the input to the climate system. Taking into account the fact that the average reflectivity, or "albedo", of the earth is 0.30 (Vonder Haar and Suomi, 1971), that

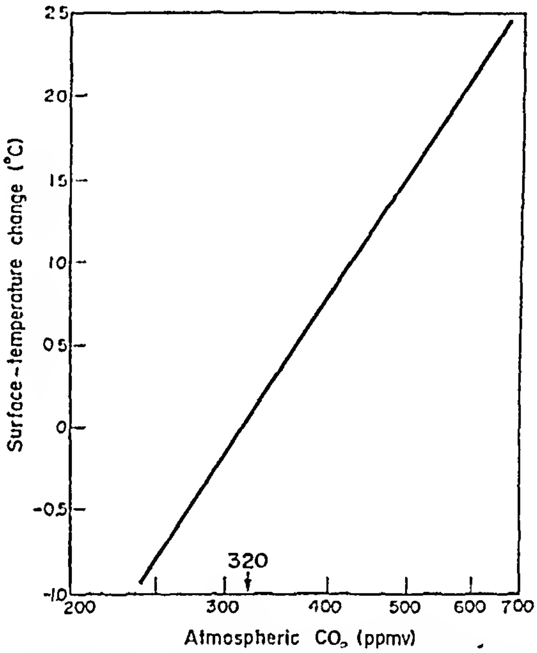

Fig. 3. Theoretical estimate of the average temperature change of surface air due to an increase of carbon dioxide from the 1970 value of 320 ppm (by volume). Adapted by Machta (1973) from Manabe and Wetherald (1967).

the average radiation on the earth is one-quarter that of the solar flux, and that only about 0.65 of the solar energy retained by the earth–atmosphere system is actually absorbed at the surface (Sellers, 1965), the global average heating of the surface turns out to be about 155 W m^{-2}, and for the whole earth this amounts to about 8×10^{7} G watts. Thus, at present human energy release is only about 0.01% of the effective solar input to the climate system, and the global effect of man's heat on the temperature must be quite trivial—though it may be significant locally.

Now let us imagine the future from the viewpoint of the "technological optimist", and sketch some more or less asymptotic approach to a world society with a stable population and a steady consumption of energy at a rate that would provide a level of affluence comparable to that in the United States now. Is this unreasonable? Figure 4 shows how the world population might behave. It clearly cannot go on increasing at the present rate of 2.1% per year, but must level off somewhere. There are those who predict a collapse rather

than a steady state (e.g., Forrester, 1971; Club of Rome, 1972), but others (Weinberg and Hammond, 1970; Kahn, 1973; Holdren and Ehrlich, 1974) have shown that from a technological standpoint the earth could sustain a population of some 20 billion people, each using some four times the current United States average per capita power of 10 kW. (The factor of 4 is an attempt to take account of the increased per capita demand for energy as food and material resources become scarcer, recycling becomes a necessity, reduction of pollution will require more energy, and so forth.) These and other considerations are discussed further by Kellogg (1974) and Häfele (1974).

If we accept this scenario of the future as one not too unreasonable guess, then 20 billion people requiring an average of 40 kW will result in a global energy (heat) release of 8×10^5

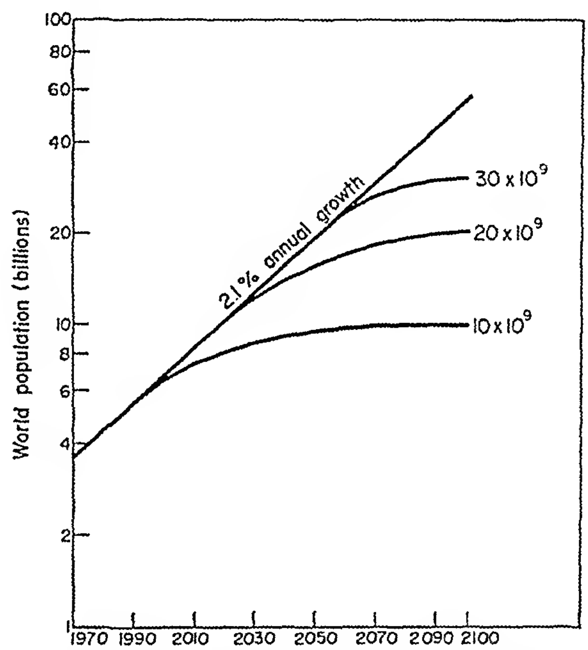

Fig. 4. Possible patterns of world population growth, starting with the present rate of increase and approaching a steady level. The present growth cannot continue indefinitely; the question is where it will level off.

GWs. This is 1% of the solar energy absorbed at the surface. Model calculations (e.g., Sellers, 1973; Budyko, 1972) that take account of some of the main feedback mechanisms in the climate system, especially the effect of polar ice and snow, show that adding 1% to the heat available will raise the global average temperature by 1.3° to 3°C, and that the change in the polar regions will be several times this, perhaps 10°C or more (Kellogg, 1974).

While these estimates of future global warming due to both adding carbon dioxide and direct heating are crude, and there are many uncertainties in the models used, the conclusion seems to be unavoidable. Unless there happen to be natural forces in the opposite direction that will act faster than they seem to have done in the last 1000 years, the warming effects of man's activities will dominate in the decades ahead and will produce a global warming that will reverse the present cooling trend. We cannot say exactly when the cooling will end, but if mankind continues to increase his rate of burning of fossil fuel and release of all kinds of energy it cannot be very many years away.

SOME IMPLICATIONS OF A GLOBAL WARMING

It is difficult, if not impossible, to describe the many environmental changes that would occur as a result of a general warming. The *mean* temperature is a convenient parameter to use to describe a climate change, but it is somewhat misleading. We have already referred to the fact that temperature changes are sure to be more pronounced at higher latitudes than in the tropics, but the patterns of rainfall may change dramatically in the tropics, as pointed out by Bryson (1973, 1974). A climate change would influence the monsoon circulation of all Eurasia, and this too would alter rainfall over large and populous parts of the world such as India and China.

Furthermore, a more detailed study of the climatic variations in the past century have revealed that there have been large regional differences in the temperature and precipitation changes that have occurred (Lamb, 1972; Namias, 1970, 1972; Kutzback, 1970; Bjerknes, 1963). This fact is indeed to be expected, since climate change of any kind will be accompanied by a shift of the standing waves in the atmosphere, such as the Aleutian and Icelandic low pressure troughs. A shift of these semi-permanent flow patterns will bring warmer air from the subtropics to some middle latitude regions, and colder polar air to others, causing opposite temperature anomalies.

The recent development of greatly improved numerical models of the general circulation of the atmosphere, as a result of better physical knowledge and the advent of high speed computers, gives us an opportunity to experiment with such changing patterns and to determine what might occur with a given change of boundary conditions. Such experiments have been carried out (Warshaw and Rapp, 1972; Washington, 1971; Williams *et al.*, 1974), but the models are still not adequate to give the detailed climatic descriptions that we would like to have. For one thing, they generally do not include the oceans as a dynamic and interacting system, and this is clearly an important deficiency that must be remedied in time. A current review of climate modeling is that of Schneider and Dickinson (1974).

In spite of all these caveats, it is useful to trace some of the more general implications of a general global warming. For example, the mean mid-latitude decrease of temperature with latitude is 0.5° to 0.6°C per degree of latitude in both hemispheres; and in central North America (100°W long.) and central Eurasia (40°E long.) the number of days and nights with frost (temperatures below 0°C) increases by about 6 days per degree of latitude. These statistics suggest that for every 1°C increase in mean temperature at mid-latitudes there will be about 10 more days in the average growing season. Such a statement gives only a part of the story, however, and the actual ability to grow crops depends more properly on the number of "degree-days", or the integral under the temperature vs. time curve in summer. Bryson (1974) shows that this can be a very sensitive function of mean temperature in marginal regions such as Iceland. Thus, a few degrees increase (or decrease) in mean temperature is likely to have the greatest impact in the cooler portions of the world.

Turning to Bryson's theory (1973, 1974) that the current Sahelian drought in central Africa is due to the current cooling trend (causing an equatorward movement of the subtropical high pressure centers and a corresponding shift of the "intertropical discontinuity" that marks a separation between the moist air moving in from the equatorial Atlantic and the dry subsiding air to the north), a reversal of this cooling trend should, if he is correct, move the rainy belt back to the Sahel. As we have said, however, the reversal may not set in for many years, and we cannot hold out this kind of relief as a solution for people who are starving today.

The polar regions will be most affected by a general warming, and there has been some speculation about the effects on the Arctic Ocean ice pack and the great masses of glacial ice on Greenland and the Antarctic Continent (SMIC, 1971; Kellogg, 1974). The Arctic Ocean ice pack is a layer of floating ice that varies in thickness from about 3 m in winter to less than 2 m at the end of the summer melting season (Fletcher, 1965). Theoretical studies have indicated that lowering the reflectivity of this ice by about 20% would cause it to disappear in three years (Maykut and Untersteiner, 1971), suggesting that the ice could be removed by a sufficient warming of the air over the Arctic Basin. However, we have no way at present to estimate how much of a warming this would have to be—a subject that certainly deserves to be investigated.

If the Arctic Ocean were to become an open ocean its characteristics would be very greatly different from the present. It would be a dark body of water instead of an ice-and-snow surface, absorbing more sunlight in summer. In winter it would present a surface of 0°C instead of around −30°C. It would add more moisture to the air that moved over it, especially in winter, and, therefore, there would probably be heavier snowfall over northern Scandinavia, Siberia, and northern Canada. Would this initiate the buildup of another ice sheet over some of these areas, as occurred during the last glacial period? This thought was the basis for one theory of the alternating glaciations and interglacials of the past million years (Ewing and Donn, 1956; Donn and Ewing, 1966), but this theory has been more or less discarded in the light of paleoclimatic evidence that shows that the Arctic Ocean has apparently been continually covered with pack ice for at least the past several hundred thousand years. So we must consider this important subject as a matter of conjecture until we can learn more about the polar ice system and its interactions with the climate.

The ice sheets of Greenland and the Antarctic contain over one-quarter of all the fresh water on earth. If they were both melted and added to the ocean the sea level would rise by about 90 m (the Greenland ice sheet alone would account for about 7 m rise). A common theme among "prophets of doom" is the spectre of the ice sheets melting and the coastal cities of the world being engulfed. Let us look at this idea more carefully. First, the ice sheets of Greenland and the Antarctic are very massive and their tops are several kilometers above sea level, meaning that precipitation on their tops will continue to be in the form of snow even when sea level temperatures are above freezing. Second, their sheer mass means that any significant changes in volume, if they should occur, will be on a time scale of many centuries at least. Third, and perhaps most significant, is the curious fact first pointed out by Flohn (1963) that the Antarctic ice sheet has apparently grown larger during the warmer interglacial periods than during the glacials, when most glaciers elsewhere were greatly extended. This inverse effect appears to be true of the Greenland ice sheet as well (Lamb, 1972, p. 485). In summary, it is simply not at all evident that the great ice sheets will melt as a result of general warming, and they may even grow larger, lowering the sea level slightly.

SHOULD WE TRY TO CONTROL THE CLIMATE?

If mankind has become so influential that he is influencing the climate of the entire earth inadvertently, does it make sense to consider a plan of *purposeful* climate control? Perhaps such an effort would counteract undesirable natural changes of climate, perhaps it could

counteract mankind's own effects, or perhaps it would merely maintain a more equitable condition and cushion the kinds of seasonal and short term anomalies that have recently caused so much distress in the world.

At first sight the idea of climate control has some appeal, and there has been quite a bit of discussion of it in both the public and the scientific literature (e.g., Kaplan, 1961; Fletcher, 1969; Kellogg and Schneider, 1974). While so far there have been no *serious proposals* to change the climate that we are aware of, there have been a number of ingenious methods suggested, some of them bordering on science fiction. These are summarized in Fig. 5, and there are undoubtedly still other ideas that will be thought of. Some depend on eliminating

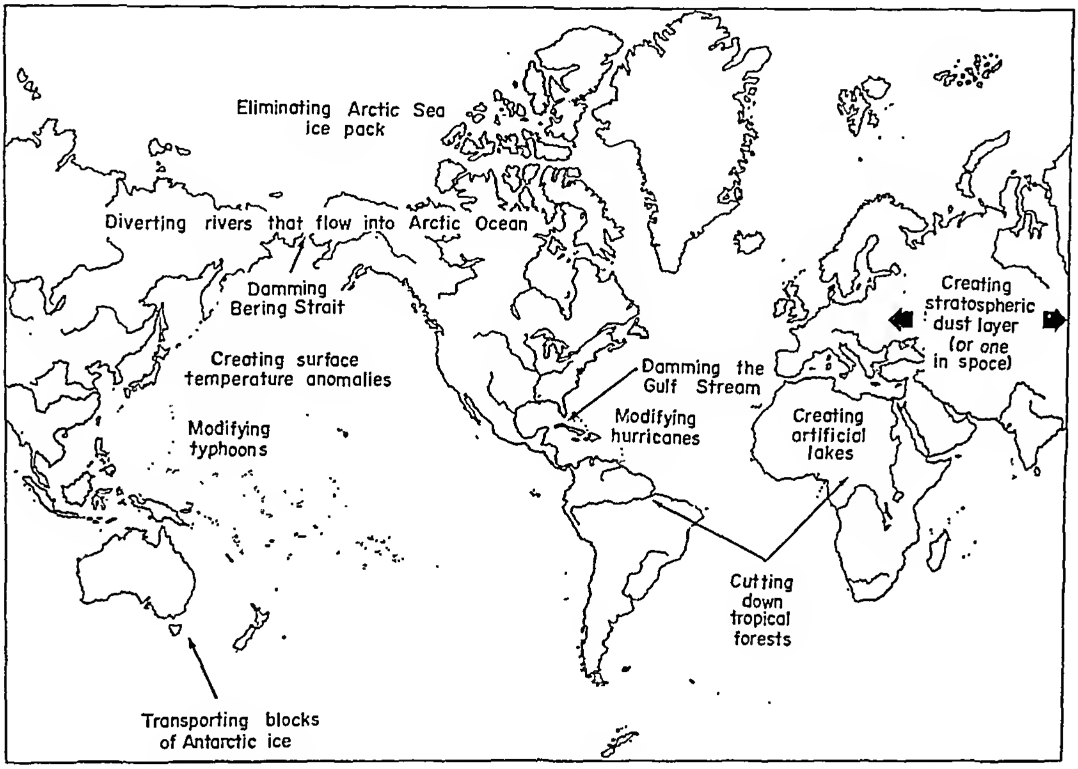

Fig. 5. Some conceivable methods for purposeful control of regional or global climate.

the Arctic Ocean ice pack (which we have already shown to be relatively sensitive to change), some depend on changing the optical characteristics of the atmosphere and thereby changing the thermal balance, some depend on massive cloud seeding or modifying ocean surface temperature in order to control hurricanes and typhoons, etc. One cannot say that they are definitely unfeasible, and the options expand if one visualizes a substantial portion of the resources of a few major countries devoted to such projects—the same amount that goes into armaments, for example.

There are several very cogent reasons for *not* embarking on any climate modification or control scheme, the main one at present being that we cannot possibly predict the outcome with any certainty. It would surely be the height of irresponsibility to try to change the environment over a large area without fully understanding the consequences, and in fact scientists from many countries have already expressed themselves as favoring some formal

international agreement on this score before some country or group of countries decides to undertake such a venture (SMIC, 1971, p. 162).

Let us imagine that at some time in the future our climate models have become so refined and reliable that we could predict in general the outcome of a climate modification scheme—and we doubt that a detailed prediction of such a complex system's behavior will ever be possible. Who then will decide on whether to proceed or not? It is most likely that a change that will benefit one region will hurt another, so any such gamble will have its losers as well as its winners. There is a certain analogy here with the struggles that have occurred over water rights to rivers that flow through more than one country, and there have similarly been heated arguments (and even violent conflict) over some efforts in the United States to modify rainfall when others in the area thought they would be deprived of "God's gift".

There is at present no established body or forum that could adjudicate such differences on an international level, unless possibly the World Court in The Hague were to equip itself with "experts" on climate. Even then, we fear the testimony of such experts would be in doubt, since the situations are bound to be so tangled that it would be hard to determine where their scientific objectivity would be swayed by political leanings.

If a country were to undertake a large scale project unilaterally, then its neighbors would be alarmed. It would not matter whether the neighbors were actually hurt by an adverse effect so long as they *perceived* an adverse effect. Who would be able to decide which was a natural fluctuation and which manmade? And who would step in to stop the effort?

We have raised just a few of the concerns that exist over the spectre of purposeful climate control. There will undoubtedly be schemes proposed that will be considered seriously in some quarters, and we suggest that more thought be given first to controlling the climate controllers. In the meantime, it is clearly imperative for many reasons that we push ahead with our studies of the causes of climate change, and that we resolve to make substantial progress here before we permit any large scale tampering with the system that determines the wellbeing of so many people.

SUMMARY AND CONCLUSIONS

There is much that we do not understand about the causes of climate change, but we have gained enough insight into the complex atmosphere–ocean–ice–land system to have a good feeling for some of the individual factors in it. The overall heat balance of the earth is one of the factors that we can assess most reliably, and we can trace the impact on this balance of changing the radiative characteristics of the atmosphere and by adding heat to it directly.

In the decades ahead there will be natural forces at work to change the climate, as there have been in the past. However, mankind's addition of carbon dioxide and the consequent increase of the "greenhouse effect" will by itself result in several degrees of warming in the next 50 years or so, if we continue to burn fossil fuels at an increasing rate—which seems likely. This effect seems to be larger than the natural changes that have occurred typically in the past century or two, and will therefore probably prevail. There should thus be a warming trend starting in the next decade or so, reversing the present cooling trend.

On a somewhat longer time scale the worldwide growth of energy production and release will, by its sheer magnitude, begin to be an additional direct source of heat that will be significant and will also contribute to a warming.

The impact of such a global warming on mankind is difficult to analyze in detail, but any change of the climate will bring with it improved environments for some and deteriorating environments for others, and a consequent shift in sources of food. With the present interdependence of the nations of the world and the small margin that now exists between enough food for all and a scarcity, the readjustments necessitated by such a shifting of agricultural patterns will certainly bring hardship to some, especially those in the less developed countries.

While the main features of a global warming do not seem to be particularly detrimental for society as a whole, there are some adverse *possibilities* that urgently call for more study as we recognize the many uncertainties in our knowledge of how the climate system will react to such a change. Perhaps the most important uncertainty in the picture is the behavior of snowfall over the land bordering an ice-free Arctic Ocean, since we cannot rule out the possibility that a new continental ice sheet might begin to form there. We do not raise this possibility as a cause for alarm, since we do not know whether or not it will occur, but rather as one outcome that would have serious consequences if it did occur and that should, therefore, be specifically investigated.

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DISCUSSION

ULAM: About 20 or 40 years from now won't it be possible to influence the climate in parts of the world? The averages in themselves maybe don't mean much. You spoke of averages as a whole and if they improved it in most habitable regions would one not understand much better the situation in detail? And the ways to influence may not be so difficult: perhaps the atmosphere circulation and the occan currents are unstable, and a small amount of energy might be able to change it? There are tremendous possibilities, it seems to me, and certainly, your institution, which is leading in the world in such studies of that, probably is aware of it; certainly it is studying the climate changes in the last few thousand years, in the Near East and other places. One can do a tremendous amount, right now, by studying the hydrodynamics, the physics in general of this problem, don't you think?

KELLOGG: There are some possible ways of modifying the climate purposefully: eliminating the Arctic ice pack, for example, damming the Behring Strait, pumping cold water from the deep ocean to the surface (if you have plenty of energy to do it), thereby changing the course of typhoons, or creating a stratospheric dust layer or putting one out in space, to reduce solar radiation at the surface, and so forth. These are on the border of science fiction, but if you imagine a large fraction of the resources of the major countries available to do this sort of thing, you could do it. Probably if we decided to do this instead of putting money into armaments we could afford it. One reason we don't do it is that we cannot predict the outcome. Our forecasting tools are far too blunt to allow us to make a sensible prediction of the outcome of any one of these things. But let's imagine that in the future, 30 or 50 years from now, we'll be so clever and our computers will be so big that we can predict the outcome of a climate control project. Would we then want to do it? I think that we would only consider this if there were an entirely new international mechanism which would make the decision. Because if you change the climate in one place for the benefit of some group, you're almost surely going to hurt it someplace else. This was a conclusion that was hotly debated at the international summer study that I attended in 1971 near Stockholm, the Study of Man's Impact on the Climate, (SMIC). There's been another more recent international conference on climate, just last summer, and I wonder if this subject came up again. Bob Stewart was there; was there any discussion of it?

STEWART: If I may answer the question: we have recently completed a conference at Wijk, in a suburb of Stockholm, on the subject of climate and climate modeling. The topic of deliberate climate change was not so hotly debated as it was during the SMIC Conference, but the discussions at Wijk were indeed relevant and the conclusions arrived at were essentially similar to the ones that you have indicated. We are at present very very far from a position of being able to say with any confidence what is causing climate change, or what would be the consequences of human activity, particularly at long distances from the location of the activity. There was support for the SMIC conclusion that the dangers of doing experiments with climate, before having this very secure information about what will happen, are too great; one should resist the conducting of such experiments. I can only support the notion you have offered that it would call for quite different international organizations from those we now have. It is almost impossible to believe that any climate change could be confined to national boundaries, or, for example, the boundaries of groups of nations such as those in western Europe. The effects would leak over such boundaries, and with present international structures that would be a source of very serious difficulties.

I should like to make one further comment concerning the outcome of this Wijk Conference—concerning carbon dioxide. Dr. C. D. Keeling of the Scripps Institute—whom Dr. Kellogg referred to as the carbon dioxide man—has done some further calculations on the ability of the ocean to absorb carbon dioxide. From some carefully conducted chemical equilibrium calculations, he concludes that the ocean's capability for absorbing carbon dioxide will in the future be rather less than had previously been estimated. He concludes that in the course of about 200 years one will have to look not for a doubling of the carbon dioxide content of the atmosphere but an increase by a factor of 10. Such an increase, if you use the appropriate logarithmic extrapolation and if you believe Dr. Menabe's calculations to be correct, could lead to an increase of surface temperature of about 8°. That's a lot!

DOSTROVSKY: It's a comment, not a question. You showed the figures on the decrease in solar intensity reaching the earth in one of your early slides. Do you have equivalent information on solar intensity outside the atmosphere? In other words, is it clear that it is something that we're doing on the earth or is it a change in the sun of some sort?

KELLOGG: I can answer that very briefly. The answer is probably NO! There is no significant change in the sun so far as we can tell.

DOSTROVSKY: Out in space it's constant.

KELLOGG: As accurately as we can measure it, which is to about 1%.

DOSTROVSKY: The other comment I wanted to make was your comment to my talk yesterday. You seemed to think that your information will be reassuring. The result of my impression this morning is that I'm even less happy today than I was yesterday. In fact I think it's very dangerous. So I don't know why you were so confident yesterday that you were going to prove to us that there's no danger at all. I personally have the feeling that you proved that there is a great danger in tampering with the temperature of the earth.

KELLOGG: I guess that's a value judgment, and everybody here may have different feelings about what constitutes a catastrophe for mankind.

BLACKSHEAR: Could you comment on the amount of carbon dioxide that would be released on clearing the rain forests compared to what is being released by fossil fuel burning?

KELLOGG: I'm sorry, but I don't know what the biomass of the rain forests is. Surely if you took them away they would no longer have the ability to absorb additional carbon dioxide, so then man's additions to the atmosphere would stay in the atmosphere longer than they do now. But I don't know the amount of carbon dioxide that would be released.

COULOMB: Je voudrais demander à M. Stewart quelle est la raison pour laquelle l'absorption du gaz carbonique augmentera tant au cours des années à venir puisque l'effet serait multiplié par 10 au lieu de 2 pour l'augmentation du gaz carbonique dans l'atmosphère.

STEWART: I am not a chemist so I have trouble talking to a chemist about this subject. However, as I understand it it is a question of the buffering effect produced by the change of pH of the ocean's surface by the absorption of additional quantities of carbon dioxide. The balance among the various chemical species is such that the pH would increase to a level to which the ocean would be incapable of absorbing more carbon dioxide at any great rate. At the present time there is some 60 times the amount of carbon dioxide in the ocean as there is in the atmosphere. But it seems that an increment in the total quantity of carbon dioxide from that number of 61 to a number of, say, 70 would put something like three-quarters of the increase into the atmosphere and not in the ocean. It appears that the ocean has absorbed most of the carbon dioxide it is able to absorb according to these calculations. It seems that the pH is already moving in the direction of increased acidity. Not being a chemist I cannot discuss this in detail.

GUERON: Il y a d'une part évidemment l'équilibre acido-basique de l'océan qui est influencé par la température mais il y a des effets plus compliqués encore parce que l'absorption du CO_2 par les eaux océaniques et sa disposition ultime sous forme de sédiment peu soluble n'est pas seulement un effet d'équilibre: il y a un effet de diffusion et un effet de transport et l'effet cinétique est plus difficile encore à calculer précisément que l'effet d'équilibre. D'autre part, s'il y a une élévation de température, il faut voir quel est son effet accélérateur sur l'absorption biologique du CO_2 à la surface des océans. Et je ne sais pas si l'on a tenu compte de cela suffisamment actuellement. Il y a vraiment beaucoup d'incertitudes et on ne peut que rejoindre la conclusion de M. Kellogg qu'une quantité énorme de recherches difficiles est à faire mais vraiment absolument nécessaires dans l'immédiat.

KELLOGG: I just want to reinforce what the previous speaker has just said, namely that the oceans have a dynamic effect. The carbon dioxide in the oceans is 60 times that in the atmosphere, and most of it is in the deep part of the oceans which have no contact with the atmosphere. So there is a time factor involved with the exchange of the surface waters, which are more or less in equilibrium with the atmosphere, and the deep waters. So over a very long period of time (several centuries at least) the carbon dioxide could be taken up by the oceans, but right now it's only added to the upper few hundred meters of the ocean that is involved in this absorption.

GUERON: I just wanted to add one figure. It is well known at the present time that half the increased input of carbon dioxide in the atmosphere is taken up by the ocean.

OIL AND THE OCEAN

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The question of oil and the ocean is one that arises quite frequently in discussing energy considerations because the most rapid growth of any large source of energy in the last few decades has been that of oil. Oil is increasingly transported by sea. Enormous quantities are now involved, and in recent years there has been a very large change in the routes used, particularly because of the closing of the Suez Canal. The canal will presumably be opened before very long, but we must not expect the routes to change back to those of 1965 and earlier because the tankers now carrying the oil are too large for any Suez Canal that will be built for some time. It should also be pointed out that there is a flow of oil now towards Japan which is of the same order of magnitude as that towards Europe.

Enormous quantities of oil are now being transported on the ocean. A good deal of it is getting into the ocean. The question then arises: does it matter if the oil gets into the ocean? I think it is easy to exaggerate the importance of this oil in the ocean. Having considered this question seriously, I have come to the personal conclusion that the importance is mostly in what you see. It's mostly extremely evident. Oil which has been on the surface for some time becomes weathered into a tarry substance not very different from asphalt. Anyone who has been on a beach in recent years must have seen it. In some parts of the world it is dense. Areas in which winds and the current systems produce surface convergences—such as the Sargasso Sea, which was called the Sargasso Sea because it is a region of convergence and bits of sargassum weed are carried there by currents and the wind—have very substantial concentrations of oil. In some places oil is coming onto beaches in massive amounts, particularly the beaches of East Africa. There is oil on the beaches of Europe. (I was in northern Portugal last year and was disgusted to find that in an area very far from any region of major industrial concentration, it was impossible to walk across the high tide line without soaking one's feet in oil.)

What does it do? It looks ugly! That is an aesthetic effect, but I have very carefully not said that it is *just* an aesthetic effect because I think that aesthetic effects are exceedingly important. In fact if we start to discuss the quality of life, towards which our attention has been turned, aesthetic effects must surely be of central importance. It matters whether the beaches are covered with oil or whether the waters are covered with oil.

But apart from that, it seems that the oil is perhaps not of tremendous concern. Many observations have been taken of the biological effect of oil in the water and on organisms

along the shore. Where the quantities are massive, such as close to an oil spill or close to a continuous oil leak, the effects can be quite dramatic and you can get very major changes in the species that exist and some important changes in the quantity. There are certain organic materials present in some oils, in sufficient quantity, can be quite lethal to a great many organisms. But it turns out that the concentrations required are such that it is not conceivable for all the amount of oil we are likely to pump in the whole history of the utilization of oil by the human race—and I think that everyone will agree that that will be a very short history, probably less than 200 years—we will not be able to pump enough oil to seriously affect the biology of the ocean as a large-scale entity. The biological effects will be local. Indeed, some recent experiments carried out under controlled environmental conditions have indicated that the hydrocarbons which get into the ocean, when diluted to the extent that one sees them over most of the oceans, will have a slight positive effect on the biology. It provides a source of energy which organisms can utilize.

Other effects have been postulated, and one should note one or two of them. It has been suggested that there are possibilities: to follow Dr. Kellogg's talk, of changes in meteorology —perhaps changes in climate—associated with oil and water. Sufficient quantities of oil on the surface of the water can importantly affect the albedo, and as Dr. Kellogg has pointed out, albedo is a very important factor in climatology. However, again, we can't pump enough oil for the quantities to be sufficient for that over most of the ocean. There are some smaller areas where you could get some effects. The Arctic is one. Oil is quite dark relative to the ice and can absorb solar heat which would be reflected from the ice. Appreciable heat is transmitted through the ice in radiant form and can be absorbed by oil under the ice. This might cause it to melt its way up through the ice column. Oil can also rise through brine drainage channels. If enough accumulates on or near the surface, since it is quite black it can significantly affect the overall albedo. That could have climatological consequences. However, again the quantity "enough" is so large that it seems unlikely that we will put enough oil into Arctic waters to affect the thermodynamics of Arctic ice on a large scale.

At the beginning of this talk I stressed the importance of transportation of oil because it is indeed in transportation that we find the source of most of the oil pollution of the ocean. There has been much concern about the effects of offshore drilling activity as a possible source of oil leaking into the ocean. I think that this concern is considerably exaggerated. It is a very very major blowout that will put as much as 300 tons per day into the water. (I know of no blowout that has produced significantly more than that.) The typical history of even major blowouts is that the flow drops to something like 100 tons a day in a very short time. Now even if this were allowed to blow freely for a year, which could happen in certain difficult areas as, for example, the Arctic, we are still dealing with a few tens of thousands of tons of oil. This is in comparison with hundreds of thousands of tons carried per individual tanker. At present it is estimated that the transportation of oil by tanker puts something like 2 million tons of oil per year into the ocean. This compares with a total world usage of oil of about 2.5×10^9 tons. Thus something of the order of one part per thousand of oil that we are using is getting put into the water from marine transportation. A substantial fraction of that gets into the water because of obsolete techniques which should be forbidden—techniques which involve cleaning empty tanks with sea water and dumping the resulting mixture into the ocean. Some ships need modification to avoid having to use this technique, but there is really no excuse for it any more. At present more than half of the oil which is getting into the ocean from tankers comes in this way, from the approximately

20% of the tanker fleet still using this obsolete technique. In comparison, the oil getting in from offshore production is at present only about 5% of that coming from tanker traffic. Municipal wastes account for substantially more than does the offshore oil production. Such simple things as the carelessness of operators of service stations who, having drained the oil from somebody's automobile, pour it into sewers. It then runs through the sewer system and ends up eventually in water.

There is a certain amount of natural oil which gets into the water. I don't wish to quote a figure on this because it is in dispute by a factor of about 100. According to some arguments as much as 30% of the total oil getting into the ocean comes from such seepage. Other estimates make the amount quite negligible. Most of the seepage seems to occur in scattered amounts in fairly deep water and it's difficult to calculate with any precision. One shouldn't be too confident about saying that it's negligible, but even the maximum estimates are significantly less than those associated with transportation.

To repeat, then, the principal source of oil in the sea is associated with marine transportation. A lot of it now is getting there by bad technique. However, even with the best technique there will still be some loss into the ocean. Oil will get into the water because of human error. Sometimes it will get into the water because of human wilfulness, and I don't know how really we overcome human wilfulness. Some time ago we had an experience in our own organization, which is a laboratory of the Canadian Department of the Environment and so we ought to care! We operate ships, and one of the sources of oil in the ocean is the pumping of bilge water from ships—straight into the water without going into the cleaning facilities that are available in some harbours. We inquired rather quietly of some of our seamen as to what they were doing and got the reply, "Oh, it's all right. We always do it at night, and we pump it across to the other side of the dock. Nobody will recognize that it comes from our ship." This from a ship of the Department of the Environment! That doesn't happen any more, but I am afraid that wilfulness still exists.

Then there is carelessness. We have queried our Navy as to why it is that so much oil gets into the water around their fuelling dock. They tell us that no matter how well disciplined their people are, and the Navy people are well disciplined, they find it impossible to get people always to turn off the valves in time. The fuel comes close to the top of the tank, the valve runs open a little too long, and some gets into the water. More serious events occur. On a location on our Labrador coast recently, at an American base, a tanker was unloading to a shore tank. After the tank had been completely filled the tanker continued to pump another tank full—all of which leaked into the ocean.

Again, there was a combination of human error and human carelessness.

Then there are troubles with ships—accidents. An examination of the kinds of accidents that happen with tankers shows that collisions, groundings, and rammings account for nearly two-thirds of the total accidents. These can only be called human error. No tanker will ever suffer a collision, run aground, or be rammed except by human error of one kind or another: failure to maintain machinery; failure to maintain navigational devices; or simple carelessness or error on the part of the navigator. By and large, then, we find that the oil that is going into the water, and having a significant aesthetic affect on the ocean, is getting there by human mistakes—human error and carelessness.

I believe that we have to recognize that humans are prone to error and we can't demand too much. Any man doing a routine job day after day will somewhere along the line almost certainly make a slip because his attention will not be sufficiently focused on what he is doing. And it is impossible to keep it sufficiently focused. There will continue to be [illegible]llisi[illegible]

and groundings and rammings. There will continue to be people who pump oil into already full tanks. We have no reason to believe that we won't continue to pollute the ocean with oil. We can, however, eliminate some of the larger causes, for example by bringing all of the ships transporting oil up to the standard of performance of the best ships. That would make a sizeable reduction, but I don't think it would eliminate it.

Does this mean that the oil in the ocean will accumulate with time? I think not. Recently our laboratory did a cruise across the whole North Pacific from west to east, examining the quantity of floating oil as we went. It was found that the concentration dropped substantially as one proceeded east and in fact by the time we reached the middle of the ocean it virtually disappeared. Now there are lots of oceanographic and meteorological influences capable of transporting the oil from the coast of Japan towards the middle of the ocean—and oil has been going into the water for long enough for them to have accomplished this. However, the very low concentrations found would indicate that there is some kind of sink which prevents the levels from accumulating indefinitely. We don't know what it is, but it seems to be there.

To summarize then, there is a lot of oil going into the ocean now, and although the quantity can probably be substantially reduced it is unlikely that we can really eliminate it. On the other hand, there is reason to believe that the oil which gets into the ocean does not continuously accumulate there, and there is also reason to believe that the principal effect of oil on the water is what you see. As far as we now know, the hidden effects are not of comparable importance.

IMPACT DE L'ENERGIE NUCLEAIRE SUR LA NATURE

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Il est tout juste possible, dans le temps dont nous disposons, de dresser le plan d'un exposé qui réponde au titre figurant au programme. Je me bornerai donc à cela, en tâchant de faire ressortir la structure de ce schéma.

Il faut d'abord *comparer l'énergie nucléaire aux sources classiques d'énergie thermique*, dans toute la série des opérations allant de la mine aux déchets.

Comme il faut beaucoup moins de combustible nucléaire que de combustible classique pour une même production d'énergie, l'énergie nucléaire est beaucoup plus légère, en amont de la centrale, que l'énergie classique.

Ainsi, 1 kg de charbon, ou de pétrole, complètement brûlé dans un foyer, fournit, en ordre de grandeur, 10 kWh *de chaleur*. La même masse d'uranium, chargée dans un réacteur industriel contemporain, donne 250 000 kWht (et en donnera 10 fois plus dans les réacteurs de l'avenir). De plus l'uranium n'est pas—et de loin—entièrement consommé: ce qui reste doit être recyclé.

Même si l'on tient compte de ce que les minerais d'uranium que l'on exploite contiennent quelques millièmes seulement de cet élément, on conçoit que les opérations d'extraction minière et les traitements nécessaires à la mise en forme du combustible sont beaucoup moins "voyantes" pour l'uranium que pour le charbon ou le pétrole. On est loin de la masse des terrils des charbonnages, des forêts de derricks des champs de pétrole. Et si imposante qu'elle soit, la masse des usines de séparation isotopique est sans rapport avec celle des raffineries de pétrole. De plus les rejets dans l'atmosphère et dans l'eau de toute la chaîne amont de l'énergie nucléaire sont infimes, si on compare cette chaîne à celle des combustibles conventionnels.

Les centrales nucléaires et les centrales classiques ne sont guère différentes dans leur aspect et dans leur emprise sur la nature (les terrains occupés sont similaires; les lignes de transport du courant produit sont identiques). Les secondes ont des rejets *atmosphériques* beaucoup plus importants—qu'il s'agisse de poussières, de chaleur ou de sous produits de combustion nocifs (le gaz sulfureux, par exemple) ou même de radioactivité! Par contre les premières, pour l'instant, demandent, à puissance égale, 2 fois plus d'eau de refroidissement. Mais ce désavantage s'atténuera, et disparaitra dans l'avenir.

La situation s'inverse quand on considère l'aval de la centrale. Les centrales à fuel produisent peu de cendres, et on peut disposer aisément de celles-ci, même si on les utilise, en partie, comme source de vanadium—métal important, dont la plupart des gens ignorent

même le nom. Les cendres des centrales à charbon sont une plaie, que nous connaissons tous

Par contre, le combustible déchargé des réacteurs nucléaires est à la fois dangereux et précieux: dangereux par son intense radioactivité; précieux par le combustible non brûlé qu'il contient. Il faut donc ou le stocker—très longtemps—sous une constante et vigilante surveillance; ou le traiter pour séparer le combustible restant (uranium d'origine et plutonium formé dans le réacteur) de déchets radioactifs qui, à leur tour, doivent être stockés sous surveillance.

L'aval nucléaire comprend donc: des usines chimiques pour isoler les combustibles résiduels et les sous-produits utiles (radioéléments particuliers), des usines de conditionnement des déchets, et des parcs de stockage de ceux-ci.

En résumé les résidus solides des centrales classiques ou sont infimes, ou peuvent être abondonnés sans risques (même s'ils n'embellissent pas le paysage). Ceux des centrales nucléaires imposent une industrie chimique délicate et l'accumulation de déchets qui exigent une surveillance quasi éternelle.

Mais il faut bien comprendre que le volume de ces déchets de grande radioactivité est relativement faible (sous forme solide, environ 3 m^3 par an pour une centrale de 1000 MW électriques fonctionnant 300 jours par an à pleine puissance). Il faut aussi bien comprendre, que, dans les conditions normales de fonctionnement, rien ne se répand dans l'environnement, et que la seule emprise sur la nature consiste en l'implantation d'usines assez petites et extrêmement soignées.

Il y a certes des déchets de faible radioactivité; et il y a les risques d'accident. Nous y reviendrons, mais il était nécessaire de poser la question dans son ensemble.

Dans l'esprit public, l'énergie nucléaire est liée à la crainte de contamination radioactive. En effet, l'industrie nucléaire met en jeu des radioactivés sans précédent aussi bien par leur intensité, par la diversité de leur support chimique, et par la multiplicité des implantations. A ce souci légitime répondent des précautions extrêmes—opérationnelles et règlementaires—pour la protection des travailleurs de l'industrie nucléaire, de la population, et du milieu naturel.

Mais le public oublie généralement—ou n'a jamais su—que nous vivons—comme tous les êtres de la biosphère—dans un champ naturel de rayonnement radioactif. Il est intérieur, car nous absorbons des éléments radioactifs naturels. Il est extérieur aussi: d'une part le rayonnement radioactif de l'écorce terrestre et de l'atmosphère; d'autre part le rayonnement cosmique, apparenté dans ses effets à la radioactivité. A ce champ naturel s'ajoutent les rayons X utilisés dans l'industrie et en médecine.

Il est important de noter dès maintenant quatre points importants:

a) le rayonnement naturel externe est très variable (dans un rapport de 1 à 4 ou 5) suivant l'altitude et la nature du sol;
b) le rayonnement interne est de l'ordre du quart du précédent;
c) l'apport moyen des rayons X médicaux est à peine inférieur au rayonnement naturel interne;
d) l'apport de toutes les activités de l'industrie nucléaire est inférieur à 2% du rayonnement externe; très inférieur donc aux variations geographiques de celui-ci.

Comme la vie a prospéré sur terre dans les conditions (a) et (b) depuis l'origine, on a des raisons de ne pas craindre (d) et d'agir sérieusement sur (c).

On sait cependant que les rayonnements sont nocifs. A forte dose ils peuvent être mortels.

La dose léthale varie largement avec les espèces; mais pour l'homme elle n'est guère que 4000 fois supérieure (si elle est absorbée en un court laps de temps) à la dose naturelle d'une année. Une dose vingt fois moindre que la dose léthale produit des effets cliniques nets.

En termes d'énergie ces doses sont infimes: la dose léthale, pour un homme moyen, correspond à quelque 600 petites calories, 1/4000 de notre ration alimentaire normale. Moins que ce qu'il faut pour une légère brûlure. Et on ne sent rien!

Mais il y a bien pire. De faibles doses peuvent avoir des effets longtemps différés (des dizaines d'années) tant somatiques que génétiques. Des mécanismes réparateurs entrent certes en œuvre. Mais on n'a pas jusqu'ici pu prouver l'existence d'un seuil de nocivité, et on doit admettre que le dommage causé par les rayonnements est proportionnel à la dose totale reçue, tout au long de l'existence.

D'où la tendance à refuser tout accroissement, quel qu'il soit, du champ de rayonnement. Et cependant, nous ne pouvons nier le fait du champ naturel dans lequel s'est développée toute la biosphère, et dont nous avons rappelé les fortes variations géographiques, sans corrélation évidente avec la vigueur ou la longévité des populations.

Les réglements relatifs aux rayonnements, de plus en plus sévères avec le temps, tiennent compte de cette situation. En particulier, pour l'industrie nucléaire, ils fixent aux émissions radioactives des plafonds absolus, et des maxima annuels, très bas, estimés inoffensifs sur les bases précédentes, et, assortis de la recommandation générale de rester aussi loin au-dessous de ces limites qu'il est possible. La pratique montre qu'on peut parvenir au dixième ou au centième.

Notons au passage deux questions importantes que nous devons aujourd'hui nous borner à mentionner:

a) il est clair, d'après ce qui précède que la biologie des rayonnements demande un effort de recherche considérable, en particulier dans le très difficile domaine de l'effet des faibles doses;
b) en contrepartie, l'effet mutagène des rayonnements ouvre, en particulier en biologie végétale appliquée, de sérieux espoirs.

L'industrie nucléaire peut donc à mon avis être considérée comme potentiellement très dangereuse, mais elle est si consciente de ce fait qu'elle est menée avec des précautions suffisantes pour ne pas accroître sensiblement le champ de rayonnement naturel.

Cette opinion est souvent et vigoureusement contestée. Certaines objections visent, en dernier ressort, l'honnêteté de ceux qui établissent, appliquent et contrôlent les règlements de sécurité. Je les écarte, mais dois les mentionner parce que, malheureusement, elles ne sont pas sans influence.

Je voudrais seulement examiner brièvement, et du seul point de vue de l'impact sur la nature (donc en écartant ce qui concerne la sécurité du travail entre autres), les objections basées sur les motifs suivants:

a) augmentation inévitable de la radioactivité ambiante;
b) risques d'accidents;
c) incertitudes sur la gestion à long terme des déchets;
d) existence de solutions techniques alternatives.

From all these plants the radioactive effluents are strictly limited and monitored by national authorities acting along lines generally approved at an international level.

Such effluents do not contribute much to the radiation burden: at most less than 2% of the range of variation of the natural radiation field; much less than the usual man-made radiation (e.g., diagnosis or curative X-rayons).

High activity waste products are never released and must be stored and monitored.

Nuclear power stations and fuel reprocessing plants are built and operated under strict systems of licensing and inspection aimed at avoiding any large scale accidents. The consequences of such accidents might be comparable to those of major floods or earthquakes. But they appear very much less probable than these natural catastrophes.

Nevertheless, research and development towards the improvement of the safety of nuclear plants of all descriptions must be, and is, actively pursued.

So must be the development of alternative primary energy sources. However, such sources do not seem able to provide, within the next 25–50 years, an industrial substitute for nuclear energy.

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DISCUSSION

LAWAND: I have a question for Mr. Kellogg and Mr. Stewart. Mr. Kellogg, I noticed in your exposé, which was very interesting, a lack of reference at all to oxygen. Although I'm not an authority on this, I'm just rather curious. There have been some studies undertaken in the city of New York already. There are certain health effects which are manifested when people go from the city to rural areas because of small diminuations in the oxygen content. I was just wondering if you had any comments on this effect? What do you think the long term effect might be on the oxygen supply? Also, what about the cutting down of those tropical rain forests? Won't that affect the oxygen supply?

KELLOGG: This matter of the oxygen balance has been raised a number of times—more, I should say, in the popular literature than in the scientific literature. In the Study of Man's Impact on the Climate (SMIC), which was a report of an international meeting in 1971, there was a section on the subject. We recognized that a lot of people are concerned about the depletion of oxygen, and we looked at the matter and found that it is almost certainly not a problem. It is inconceivable, in our opinion, that the balance of atmospheric oxygen could be greatly changed by anything that man could do. You would have to wipe out all plant life on the earth to have much of an effect. The life in the ocean contributes some oxygen, but even if by some mechanism you were to wipe out the plant life in the ocean, even this would not have a large effect on the oxygen balance.

LAWAND: . . . I was just curious whether the graphs which have been taken in great detail on carbon dioxide level had been also done on oxygen level. Has that been done and is there any effect? (Affirmative answer by Kellogg). Thank you very much, that's quite reassuring. My next question is to Dr. Stewart. Though I agree with you that the oil is ugly, I was curious as to the nature in which it disperses itself on the ocean surface and whether any studies have been done in depth on its effect on evaporation.

STEWART: Yes. This topic has been studied. On the ocean surface a new oil spill will produce a layer of a liquid which can be quite thick, sometimes of the order of several centimeters and quite frequently of a few millimeters. In such a condition evaporation is completely inhibited. However, if you do a calculation even of a massive oil spill, the area covered at such a thickness is of the order of a few hundred kilometers square (a million tons of oil spread uniformly over a square 100 km on the side would be only slightly over $\frac{1}{10}$ mm thick). Such an area is small compared with the ocean. In practice, within a couple of days the light fractions of oil evaporate and leave only the heavy fractions. These interact with the water to produce a variety of materials including mixtures of oil in water and other mixtures of water in oil, most of which float but some of which don't. The material formed tends to cluster into little clumps ranging in size from about that of a pin head to things that sometimes weigh as much as a ton. These gatherings are now so scattered throughout the ocean that there is virtually no effect on evaporation at all. Thus, although there is an appreciable effect on evaporation over a small area immediately after a spill, the effects on the evaporation on a large scale over long periods of time are quite negligible.

LAWAND: It's not then dispersed in thinner and thinner layers? It actually coalesces?

STEWART: That is right. After interaction with the air and with the water the resulting material coalesces.

LAWAND: . . .It's on both these points on the oxygen and oil and other factors that one sort of worries when we see projections, for example, for increasing our power consumption by 4 and 5 times what the long term effect of these effects might be.

LEWIS: Although Dr. Guéron was most encouraging, I think I can give you a little more encouragement concerning the management of radioactive wastes. I have a publication, now two years old, *Radioactive Waste Management in the Long Term*. The particular trick of this was to turn yourself around in time. If you suppose that you are operating a plant, looking after radioactive wastes, and there is a constant supply coming in, you will find your greatest concern is the wastes that have come in from the power reactors in the last 10 years, because they are more highly radioactive, their heat output is greater, and in fact if we make an estimate of how much of your effort would be spent on the waste from the last 10 years and then all the wastes cumulatively, back to infinity—actually I only took it to 2000 years but one can see it going on that way— that the old wastes involve a much smaller effort. That is to say you do not need a vast and impossible space for looking after 300 million kWts. The active bed of the old wastes—let's say beyond 10 years— after 2000 years would only be 2 m deep and half a kilometer square. One can think of this being in the plant that you are operating, looking after all the new wastes. Let us say that looking after 300 million kWs in that way for a world generously supplied with energy, perhaps the total number of plants in the whole world would only be 1000.

BLACKSHEAR: After what length of time and what power level?

LEWIS: What I was saying here was that looking after the wastes from 300 million kWs, actually on the thorium cycle, but that was the only one I was interested in in the long term, the bed of the highly active wastes in the last 2000—forgetting the last 10 years—just go back, going back 2000 years—that bed would be quite small: 2 m deep and 0.5 km square. The heat energy from this plant mostly comes from the waste of the last 10 years. The total energy out would be 2 million kWs thermal, which is much the same as the requirement for siting a single small nuclear power plant.

BLACKSHEAR: After 2000 years, that's all the waste you have?

LEWIS: Yes.

GUERON: What Dr. Lewis has said is entirely true. You must, nevertheless, qualify it in this way: this is true of a waste deposit in which no incident occurs. You must, nevertheless, organize and police your deposit so as to take care of accidents occurring on young as well as on old wastes. This would complicate matters a little.

LEWIS: If I might just come back on that point. The basic idea of this plant is that it would be surrounded by what sometimes I call a "moat", a sort of no-man's land. If any radioactivity escapes into the moat it is easy to process air or water—and the moat would be water with air over it—to bring the level of activity down so that you can either put it back into the moat or back into the biosphere, while putting the radioactivity back from where it escaped.

KELLOGG: I would like to ask M. Guéron a question. He mentioned various possible places in which to store the radioactive waste material. One of them was in an ice sheet where the heat could melt the ice underneath it and would finally rest at the bottom of the ice sheet. A proposal has been made (by an individual not here) that such waste be put into the Antarctic, which is a long way away and is generally considered as international territory. Apart from the fact that an international agreement would probably be very hard to reach, a few months ago I listened to a debate by a group of glaciologists who considered this proposal to see if they had any reason to agree with it. There was general disagreement. The reason for disagreement was that they were given the boundary condition that this radioactive waste should be kept out of the open part of the system for about 500 000 years. That is such a long time that we simply do not know how to predict the motions of these great Antarctic ice sheets well enough. We can't guarantee that it will not be coming out into the ocean in the course of such a long period.

GUERON: I'm sorry, Dr. Kellogg; probably the translation led to a misunderstanding. You must realize that when I spoke of this solution—which I think, incidentally, was first proposed concerning Greenland by a German scientist—it smelled of air bombings because he proposed parachuting the cans from planes. I mentioned such solutions as futuristic, in a somewhat humoristic way, in particular the case of ice burial. I stated that of course you could not rely on this. I feel that the variant which considers melting rock, and going therefore very deep, is much more serious. But again, it is futuristic. At the present time you have no alternative but to control the waste. I might mention also one more futuristic idea which is to put the waste in the rift where the tectonic plates come under one another, not where they separate but where they converge. Then the waste would go into the mantle. Well, all these are impracticable were it only because of the necessary long distance transport. The deep burial looks much more feasible. But you must realize that in all such proposals the radioactive mass will have been carefully enclosed and before that embedded into a solid of very low chemical reactivity. Nevertheless, safety evaluations assume a very fast release and extremely quick leaching out of radioactive material from this chemically inert mass. It is reasonable to assume this because you always have to put yourself in the worst case. But you also have to estimate probabilities of the worst case—not only the possibilities, but the probabilities. This is extremely important. It works on the same sort of reasoning that people object to sea burial of low activity waste. Because if everything you put at one time was immediately released and leached out on the spot—if there were at this spot no natural fixation mechanism by sediments—then you might have something dangerous in a limited way. It is reasonable to assume this for safety. It is unreasonable to assume it as a probability.

CAPRIOGLIO: I should also like to make a comment on Dr. Guéron's exposé, particularly on this very important question of disposal of waste from nuclear power stations in the long term. I should like to make the point that this highly radioactive waste in fact can be distinguished into two portions: one is the alpha active portion, which is in fact the one that is particularly dangerous at very long term. One is talking about thousands or tens of thousands of years. And the non-alpha decaying waste of fission products, which are much shorter-lived and much easier to dispose of. If one makes the separation—and this can be economically sensible once mankind would have very large amounts of waste to deal with—then it becomes feasible or conceivable (and I think economically viable) to burn the alpha active waste in nuclear reactors. This would practically eliminate them and make new fission products which can be disposed of. This is something I think is well worth examining, at least among the futuristic lines mentioned by Dr. Guéron.

BLACKSHEAR: I wonder if I could ask Dr. Stewart to apply some of his experience in the oil field where, as he mentioned, accidents were inevitable and that willful misuse of procedures was inevitable in almost every operation. You have experience that suggests that 1 part in 1000 of the oil handled escaped into the atmosphere. Can you apply this to what you just heard from the nuclear establishment and their high

hopes of far tighter control on emissions? Finally, I would like to address the question of the inventory of unaccounted for nuclear fuel, Dr. Guéron, after Dr. Stewart has replied.

STEWART: I should emphasize that although from time to time I work in association with the oil companies I am actually in the Canadian Federal Department of the Environment. To respond: I think that there is no doubt that errors, indeed almost any conceivable error, will happen sooner or later. No amount of caution will prevent all errors. There is an old saying that you can make things foolproof, but you can't make them damn-fool proof. Unfortunately there are a lot of damn fools around who deliberately, purposefully, eliminate all of the safeguards that have been put in place for their protection or the protection of others, in order to eliminate even minor inconveniences to their activities.

GUERON: I would like to qualify your question in respect to my talk. I was asked to talk about the impact of nuclear energy on nature. I can specifically say that I was excluding the questions of plant safety and so on. But you must realize that when you speak of unaccounted for nuclear fuel this simply means that in any system of control you cannot make the balance fit to exactly 100%. You have a margin of error which you can reduce more or less, and here you have a law that the difficulty or the cost, grows exponentially with the efficiency. But if your balance—and we're now going out of the problem of the impact on nature—does not fit to 100% it does not mean that you have a loss or that you have had a theft. It means that you don't know. In most cases you will have had neither loss nor theft. You will have had accounting errors in your processing system, somewhere in your chemical determinations, in your volume estimates or in your computations. When you have this risk of fault, the risk is not an impact on nature—and I did not cover it—the risk is that of a willful diversion. That's quite another problem. It is not at all easy to willfully divert dangerous material. It's not so easy to sabotage a nuclear plant. And we can talk a lot about this. But this is not the subject I was asked to deal with.

BLACKSHEAR: But could you give us an idea of the magnitude of the unaccounted for fuel? And if it all were in nature, the amount of damage it could produce?

GUERON: Everyone with experience of a chemical plant knows that a material balance sheet which fits to within 1% is very good indeed. There is no mining plant, there is no refinery, there is no metallurgical plant where you can have accounting certainty, that what you have put in plus what you have as waste plus what you have produced fits to better than 1% of the inputs. You would need enormous expense to make it fit to 0.1% or closer. But again, the fact that it doesn't fit in that way does not mean that the difference—which may be an excess rather than a deficit, mind you—has been stolen, willfully diverted in a completely uncontrolled manner, or spread in the nearby environment. But there are very sensitive detection devices which would detect people carrying out these radioactive or fissile materials. This provides tests entirely independent of whether your materials balance sheet does or does not fit better than 1% or even 0.1%. So when you look at or play with these sort of assumptions, you must be extremely specific, otherwise everyone, every answer, can get into terrible nonsense.

BLACKSHEAR: Over and above the error of 1% or whatever the precision might be, there was substantial unaccounted for fuel in the United States. I wondered if with your experience in Europe there was a similar large, unaccounted for balance over and beyond the normal chemical plant precision?

GUERON: I have not been directly responsible for such things in an operating plant. I know that there have been a number of examples of lousy operation, they did not concern very great amounts in absolute terms, and I would say that the fact that they have come to light is a good thing.

LAWAND: Again for M. Guéron, and I assure the sentiments of my colleague from Minnesota; I'm not quite as optimistic. Perhaps Dr. Lewis could help answer this question as well. I'm not in the nuclear field. I'm just curious. Is any research being done to try to—I don't quite know what the term would be—to neutralize or dispense with these wastes in some other manner? Or is storage the only consideration? I know in your field it may be an obvious question, but I remember reading quite a while back that some crackpot claimed that he could neutralize these wastes. Is there anything in that at all?

GUERON: Well, Dr. Caprioglio mentioned one case. You cannot do anything with radioactivity except by nuclear methods. This is not easy and it is expensive. Dr. Caprioglio mentioned that if you could separate from the waste (apart from the fission products), the alpha active isotopes, some of which are very long-lived, then you could dispose of them, transforming them into short-lived activities by putting them in nuclear reactors.

LAWAND: Excuse me. Could you define short-lived?

GUERON: A few years instead of a number of centuries. Sometimes seconds. For some of these products you have an enormous range or half-lives, but the worst would have a half-life of a few tens of years instead of a number of centuries, and it would be an improvement. But, as he pointed out, this corresponds only to a small fraction of the waste. The bulk waste, as Dr. Lewis has rightly pointed out, is mostly that of the last 10 years.

LEWIS: Perhaps I can give a little comfort. I have retired now. I have had a long experience, in fact since 1930, handling radioactive materials, including some 20 kgs of separated plutonium. We've handled this. We have the accidents, we have stupidities, we have all these things, but one goes at this in a practical way. For example, one may have a fire in a fume hood with plutonium. The practical method is first of all to stop

the fire, then, with the usual gas mask or complete protective suiting, to approach with a paint spray gun and spray all the exposed surfaces, because the hazard from plutonium is that it becomes airborne as an aerosol, that one would then breathe, and, in the long term, something might stick in the lung and there might be trouble. So you go about it in this way, just suited to the particular trouble that you've encountered. What we can say is that we have found a practical method of dealing with every situation that we've encountered. I think the most difficult one was in 1952 when we had about 10 000 curies of various age fission products in a million gallons of waste water in the basement of the reactor building. Well, we restored the reactor. It's given very great service since and we have not encountered any radiation trouble that we know to any of the workers that were involved there. We believe that we know that the situation is satisfactorily under control. Naturally, plutonium and other things are there in the wastes. But again, this question of a waste. Why do you leave plutonium in a waste? That is because it is difficult to take it out. It is equally difficult for the animal—human or otherwise—to take it out, to do some damage to himself. I think—if he wanted plutonium—he wouldn't look in the wastes. He'd look to see if he could steal it from a better place. So that one has to make the access to the more concentrated material difficult in several degrees. We usually work on the principle of multiple barriers. Again, you have to put in the multiple barriers to the extent necessary. I will say this: working in radioactive plants with large amounts of radioactivity, you do have to take steps that are not taken in an ordinary plant. But over the years—things always look a little frightening when you first come upon them and realize that this is something you're going to have to do, but when it comes to the point, you find that there are some very obvious steps that you take. I feel that one of the greatest things we've got to beware of is extending the commercialization of this business, because there you find, let us say we have shipped plutonium from one place to another and the accounts always show that less arrives than departs. You know that this is a human failing and not a real occurrence. It is simply that everyone is afraid that they may lose a little and, if they have not taken on quite as much, it's a little better. Unfortunately this means that one must avoid as much as possible these shipping transactions of handing over of responsibility from one to another. This is part of the philosophy I've developed in the matter of handling wastes: that these are not shipped out; some go back to the reactor; there is recycling within the plant and there is this radioactive storage. But I feel that there is a lot in this philosophy and I feel quite hopeful that the realities of the situation will force the human beings of the future operating on so large a scale to adopt practical measures.

DOSTROVSKY: I think that the sanguine attitude which is taken by the nuclear industry with respect to the questions we've just been dealing with is really not justified by the history. Your question was obviously a loaded one, potentially. I mean you know very well that hundreds of kilograms have been floating around unaccounted for in the United States—everybody knows this; it's in the papers. We also know that plutonium is found outside the confines of various plants in the United States—in the ground, in the soil—which means stuff is escaping. We've had this leakage at Handford and we had the Windscale accident, so the history shows what you've said, Doctor, that the people in the nuclear industry are not more infallible than in other parts of industry. They're human beings. I think it's not a question for engineers, but psychologists. I don't think there's any chance of a human being suddenly turning up to be a perfect error-free machine. Therefore I think that one should be prepared for the fact that there will be dissipation. I'm not talking about diversion. I'm talking about really genuine errors, mistakes, and so on. Dr. Guéron mentioned 1%, which is tremendous if you translate it into the amounts of plutonium that will be going around the cycle in a few years. It may mean that tons of plutonium will get into the environment. This 1%: for all I know it may be stuck in little bits of filter papers in the various plastic bags that are revolving around in the waste disposal cycles. I don't know. But you have to assume that it is going to be in the environment. So, altogether, I don't think the question should be swept under the carpet. I think it's a serious question; it relates to limits of human abilities. We're dealing here with a subject that is quantitatively different. Up to now the things we've been doing have been more or less within the limits of human abilities, and we've lived with it. Now I think we're getting into a matter which really taxes the ability of the human being to really control entirely, and I think we should be fully aware of this qualitative difference. One little point about what Mr. Lewis has said. You know that the long-lived products, of course, accumulate in the area—you don't get the steady state in the year 2000 in plutonium. So the steady state you seem to indicate on the fission products, certainly is there, for the relatively shorter one—hundreds of years already is short-lived on that scale. But the long-lived materials will, of course, keep on building up for thousands and thousands of years. If we are talking about 500 000 years or something like that, then maybe we reach a steady state. I don't argue about this point. I'm just saying that plutonium has a long half-life and you're not going to reach a steady state on plutonium until 100 000 years from now. That is a mathematical fact. There is no argument about that. So you're not going to reach a steady state, you're going to build up.

LEWIS: My report that I quoted is not a long report but has a lot of detail. Plutonium is, of course, valuable; we want to get as much back into the reactor as possible, if not at the first recycle then at a later recycling. The idea is that if we are putting anything into the environment, then it is something that is monitored at these multiple barriers to keep radioactivity from just falling into the environment. In these moats we're looking for it; if we find any there has to have been a major error in the system. Let us point

out that the experience that has been in the newspapers, from the United States, and others, all concern actions that perhaps people have learned from so that they won't do it again, because they aren't necessary. I can't recognize a scenario like that in the Canadian operation. We're on a much smaller scale and I don't want to pretend that we've had any of the problems that have come up in the United States. But I think we have a plan.

GUERON: Of course I could not go into details. I wanted to stay within my assigned time. But to re-emphasize and reinforce what Dr. Lewis said, I want to state this. Is it true that there has been the Windscale incident and others. I mentioned them briefly by saying that they had had no outside effect of any importance. In the case of Windscale the milk from a limited surrounding countryside was destroyed for about two weeks. That's all and there's nothing left. The fact that some plutonium is found in the vicinity of plants is true. And it leads, as Dr. Lewis has said, to reinforced measures and more careful operations. The leak in the Hanford tanks is typical of mismanagement and sloppy procedures. But what is significant also is that you have seen here the efficiency of a natural barrier which is widely not taken into account. It is the enormous capacity of soil and rocks of all description to fix very solidly a great variety of chemical species and to leak them out only very, very slowly to the environment. We must not make that one of the voluntary barriers, of the multiple voluntary barriers, which are the rule of nuclear energy as Dr. Lewis pointed out. But we must not either ignore that it exists and that it is a sort of natural safeguard against us.*

BLACKSHEAR: I hate to beat this dog too hard but I think we do have a very valuable recourse here: the experience of the oil industry. If I can just say once again what Dr. Stewart said was that it is not in the early stages or the exciting research stages or the exciting first round of employees in any business, but it's the old deadening routine where accidents and carelessness occur and where diversion is possible. I think that the possibility of accidents occurring is inevitable; the possibility of diversion is almost inevitable. I have a feeling that we're not doing humanity a service by rushing in to deploy nuclear energy before we can exhaust all other possible means of bringing energy to humanity. The possibility of diversion and of accidents is such an appalling sword to hang over humanity. The two questions I have for the strong nuclear proponents which we seem to have in abundance here are: (1) If there were alternatives, would you, the proponents, recommend deferring deployment of nuclear energy until these alternatives were exhausted? (2) Considering the scale of technology or the level of technology that's required to maintain the safeguards, would you recommend deploying nuclear energy in developing countries at this point?

GUERON: I would like to say that if there were alternative technologies, and if the impact on nature of these alternative technologies had been explored to the same extent, then I would prefer other technologies. But, first, these technologies do not exist and they are not around the corner. It may be because of a mistake somebody made 30 years ago; all right. But they do not exist and they cannot be developed and deployed within the next 30 years on the scale sufficient to replace nuclear energy. Second, I am certain that as any technology gets nearer to deployment, good and bad reasons, or good and bad motives, will detect increasing impact on nature. Third, as to whether you should develop nuclear energy in developing countries: it's a matter of balance. We have had examples, such as the incident which happened in Yugoslavia, showing that you have more risks with an advanced technology in surroundings where the degree of technological awareness is somewhat lower. On the other hand you say accidents will occur. So do we. Simply the ratio of the effort going into production to the control and surveillance is a function of these dangers. If there were no more awareness and no more care in nuclear plants than there are on building sites, you would see another story. But we are aware of the things and we take the precautions in design, in building, in operation, in control. There will be accidents. There will be faults. But don't imagine that it is easy to get in and go out with a kilo of plutonium in your pocket.

LEWIS: I have a paper coming up this afternoon and therefore I will only say one little thing for those who may not see the paper this afternoon. My scale of cost and benefits—the benefit that I'm looking for is the alleviation of poverty and starvation in the world. The cost is taking this particular care and special trouble and planning necessary for abundant nuclear power.

* (*Note added in proof*)

It has been shown that a natural nuclear reactor operated spontaneously in Gabon, for many centuries, about one and a half billion years ago, and that since then all the fission products so formed have essentially stayed put, on the spot.

Chapter IV

IMPACT OF ENERGETIC SOLUTIONS ON SOCIAL, POLITICAL, AND ECONOMIC LIFE

Président: G. RANDERS

CONTENTS

INTRODUCTION

G. Randers

It is obvious to everybody that our choice of energy production methods in the future is going to influence heavily our way of living. A year ago, when I was still with the Science Division in NATO, we had a symposium considering what would happen if *only* energy considerations were governing the future of societies in the Western world. I think it was a consensus that we then would end up with some kind of science fiction situation: people living in caves beneath all their machinery needed for making energy and producing food. This is obviously a satisfactory solution from a pure energy point of view, but what we are going to discuss today is whether we are forced to, or want to, make such a choice for the future. What can we do to find a more acceptable life, where energy is not the sole factor deciding what we are going to do and how are we going to live, but where energy will be put in its right place together with other factors?

IMPORTANCE ET LIMITES DU FACTEUR ENERGETIQUE DANS LE DEVELOPPEMENT DU MONDE

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INTRODUCTION

Depuis la fin de la seconde guerre mondiale, les économies occidentales et celles de notre pays notamment se sont placées sous le signe du développement, du progrès continu. Nécessaire d'abord pour faire face aux besoins de la reconstruction d'une Europe dévastée, cet effort a été maintenu par la suite en vue d'améliorer le niveau de vie des citoyens et de diminuer les écarts qui les séparent. Il est vite aparu de plus qu'un vaste problème se posait aux Nations nanties: apporter leur aide aux peuples qui n'avaient pas encore pris part au développement industriel de façon à réduire aussi les inégalitée entre les Pays.

Mais ce développement économique a une contrepartie qui vient de s'accentuer depuis quelques années: nous sommes en effet quelque peu pris de vertige, à la réflexion, devant cette poussée sans limite. Ceux qui réfléchissent au destin de l'homme sont frappés par les énormes consommations et souvent les énormes gaspillages de matières premières qu'entraine le développement ainsi que par l'accumulation d'effets nocifs qui deviennent sensibles à tous. On doit se demander si l'allure peut continuer à être indéfiniment accélérée. C'est cette question que se pose l'Institut de la Vie. L'énergie constituant à plusieurs égards un révélateur intéressant, son Président le Professeur Marois m'a demandé de l'aborder sous cet angle devant vous.

Un examen rapide des développements passés parait s'imposer pour éclairer l'avenir.

I. ENERGIES ANIMALE ET VEGETABLE

L'énergie solaire qui a été longtemps la seule source d'énergie pour la planète, a été utilisée d'abord (avec une cascade de rendements catastrophiques) par l'assimilation chlorophyllienne, laquelle fixait le dioxyde de carbone de l'atmosphère pour la constitution des tissus végétaux; ces tissus à leur tour servaient de nourriture à l'homme, soit directement, soit en passant par l'intermédaire d'un animal.

Pendant des centaines de millénaires, le seul moteur était le muscle, celui des hommes surtout et un peu celui des animaux.

L'agriculture a constitué un premier progrès technologique qui a permis la concentration

de l'énergie en améliorant, sinon l'assimilation chlorophyllienne, du moins l'accumulation de ses effets, notamment dans les graines des vététaux; de son côté l'élevage permettait une concentration analogue, les bêtes étant chargées de ramener au point où elles étaient sacrifiées l'énergie répartie dans les paturages, sous déduction, bien entendu, d'un rendement assez médiocre. L'utilisation de l'énergie musculaire animale était très modeste et surtout employée lorsqu'une force importante était nécessaire, comme pour le labourage ou la traction des véhicules. Pour le reste, l'esclavage ou ses substituts semble avoir été une solution plus facile à mettre en œuvre que le dressage des animaux.

Un autre progrès considérable a été réalisé par l'énergie végétable: j'entends par là l'utilisation directe des produits carbonés contenus dans les plantes et notamment dans le bois. Le feu a permis à l'homme de découvrir un certain nombre de techniques dont le rôle, dans l'évolution préhistorique, a été considérable: on en veut pour preuve que ce sont précisèment ces technologies qui servent à repérer les époques en cause: l'âge du bronze, l'âge du fer . . .

II. L'ENERGIE MINERALE

Passons rapidement sur toute la période historique et venons en au XVIII^e siècle: deux novations considérables se font jour, appuyées d'ailleurs l'une à l'autre: la machine à vapeur et l'extraction de la houille. Il est à cet égard significatif que la première machine à feu fut utilisée précisèment pour une pompe à exhaure: celle de Javerie, qui date de 1699. Lentement au XVIII^e siècle, puis beaucoup plus rapidement au XIX^e, la grande révolution industrielle se produit: elle est caractérisée par une concentration de main d'œuvre sans précédent, sur et autour des gisements de houille.

Le chemin de fer intervient alors et, vers la fin du XIX^e siècle, la société industrielle prend le visage que nous lui connaissons bien. La sidérurgie prend son essor. Enrichies par l'industrialisation, les grandes villes billent d'un éclat encore jamais atteint. En même temps, ces grandes concentrations et ce grand déséquilibre des revenus sont générateurs de luttes sociales. Les mouvements ouvriers politiques et syndicaux s'appuient sur les notions égalitaires issues de la Révolution Française. A peine construit, le capitalisme est assiégé.

Au XX^e siècle le pétrole entre en scène. Ses progrès sont modestes d'abord, puis atteignent un rythme impressionnant. Les hydrocarbures (pétrole et gaz naturel) représentent, dans la consommation mondiale:

— en 1913, environ 5% d'un total de 0,9 Gtep.*
— en 1950, 37% d'un total de 1,7 Gtep.
— en 1972, environ 66% d'un total de 5,1 Gtep.

On notera que la consommation mondiale d'énergie globale n'a augmenté, en moyenne, que de 2% par an de 1913 à 1950 alors qu'elle s'est accrue de plus de 5% par an entre 1950 et 1972. La consommation de pétrole de son côté, a été l'objet d'un accroissement de 7,5% par an au cours du dernier quart de siècle.

Comme la houille, le pétrole se trouve dans des régions ou il est concentré de façon privilégiée. Toutefois, à la différence de la houille, ces gisements sont distribués de façon extraordinairement inégale: c'est ainsi que le Proche Orient constitue une accumulation sans équivalent dans aucun autre domaine: sa part dans la production pétrolière mondiale a triplé en un quart de siècle passant de 15 à 45%, tandis que le marché auquel s'appliquent ces pourcentages a quintuplé pendant le même quart de siècle.

* 1 Gtep = 10^9 tep = 1 milliard de tonnes de pétrole ou de son équivalent thermique.

Concentration de la production mais, grâce à de grands tankers et aux pipelines, la diffusion des ces gigantesques ressources énergétiques se fait avec une aisance sans cesse accrue et à des coûts de plus en plus bas. Il reste que pour les industries mettant en œuvre de très gros tonnages, les zones portuaires proches des terminaux pétroliers, constituent un emplacement de choix. Cependant cette localisation ne dépend guère de la proximité des lieux de chargement du pétrole, le coût du transport par met étant fort peu sensible aux distances. D'autre part, dès qu'il s'agit d'industries plus légères, la commodité d'emploi des combustibles liquides et la facilité de leur transport donnent la plus grande liberté pour leur localisation. A l'inverse de ce qui s'était passé pour la houille, cette nouvelle vague d'industrialisation peut s'effectuer en surface sur l'ensemble d'un territoire comme celui de l'Europe Occidentale ou des Etats Unis. L'automobile et la route ajoutent leurs commodités pour réaliser cette égalisation des conditions industrielles. Corrélativement, on voit s'effectuer également une sorte d'urbanisation en surface, et l'importance que les villes moyennes ont prises sur l'échiquier politique est bien caractéristique à cet égard.

C'est la grande époque où le Japon et l'Europe construisent non pas seulement une nouvelle économie, mais la forme de civilisation qui en est le corollaire, sur le pétrole des autres.

Précédés de nombreux signes annonciateurs, les événements de 1970 ont mis les Nations industrialisées devant le fait de la puissance qu'avait construit patiemment le cartel des pays exportateurs de pétrole. Cela n'a du reste pas suffi et il a fallu 3 ans encore pour que les séquelles de la guerre Arabo-Israélienne de 1973 fassent brusquement vaciller l'Occident. Encore faut-il observer à cet égard (et je ne m'étendrai pas davantage sur ce point) que personne n'a été privé de pétrole au cours des mois qui ont suivi. L'embargo a été entièrement compensé par le jeu des échanges entre les mains des opérateurs et la production d'ensemble n'a subi aucune réduction, les restrictions des uns ayant été largement compensées par les augmentations des autres.

Il reste que le coût du pétrole brut pour les pays importateurs est devenu brusquement un élément majeur de leurs échanges internationaux. Non seulement il en est résulté un déficit de la balance des comptes pour les pays placés dans une situation relativement fragile comme l'Italie ou, à moindre degré, la France.

C'est aussi l'ensemble du système des échanges monétaires et économiques internationaux qui a été mis à une épreuve dont il n'est pas sorti à son avantage. Il est aujourd'hui impossible de mesurer qu'elles seront les conséquences à long terme de ce phénomène brutal. Il est seulement à prévoir que, comme toujours en cas de crise, ce seront les plus forts qui se tireront de cette mauvaise passe dans les conditions les meilleures.

On peut noter ici l'étrange démobilisation qui semble caractériser l'Europe à l'égard du problème de son approvisionnement pétrolier. Aucune mesure d'ensemble destinée à réduire sensiblement son approvisionnement n'a réellement fait l'objet de décisions dans les principaux pays et moins encore à l'échelon communautaire. Il semble cependant que dans une période inflationniste comme celle que nous connaissons, la régulation par les prix est tout à fait insuffisante. Les tenants des mécanismes dits libéraux semblent n'avoir encore pas compris que ceux-ci sont incapables de résoudre un certain nombre de problèmes tels que celui devant lequel nous nous trouvons placés, du moins si l'on exclut certaines conséquences, politiquement insupportables de l'aveu général. Il parait peu probable que l'Europe sans doute, la France en tout cas, puisse éviter d'avoir recours à des mesures faisant un peu plus appel à l'imagination et au civisme que de simples hausses des prix.

III. L'ENERGIE ATOMIQUE ET L'AVENIR

A l'inverse de la houille et du pétrole, la nature de l'atome n'est pas concentrationnaire quant à ses ressources: l'uranium est un métal assez répandu du moins à très faible teneur et l'importance de son prix dans celui du produit final, savoir l'énergie utilisable, est faible.

Cependant l'énergie nucléaire met en œuvre une énorme concentration dans un autre domaine: la technologie.

On pourrait ici faire une parenthèse et tenter de dresser, en parallèle avec le tableau économico-sociologique que nous avons tenté d'esquisser, un schéma de l'évolution des questions énergétiques dans leurs rapports avec les problèmes d'armement et plus généralement avec la polémologie. Mais il ne saurait être question ne fût-ce que d'aborder cet immense sujet.

Dans le domaine nucléaire, la puissance américaine, héritière de la technologie de la "bombe" est aujourd'hui manifestement sans rivale. Malgré l'accession de la Russie, puis de la Chine, au rang de puissance nucléaire, les applications civiles tirées par l'une et l'autre sont restées jusqu'ici modestes. Est-il besoin de rappeler que les efforts français et anglais en matière d'uranium naturel, que la remarquable percée technique de la Suède sur les réacteurs à eau ordinaire bouillante, n'ont pas trouvé leur issue? Au mieux, ces efforts auront pour retombée une certaine familiarité des industries en cause avec le caractère particulier des techniques nucléaires.

Cependant, il n'est pas douteux que l'atome apporte la clef de l'avenir dans le domaine de l'énergie. Il est hautement probable qu'à la fin du siècle—et non sans peine, certes, mais par des efforts et aux prix d'investissements qui ne paraissent pas hors de portée—la quasi-totalité de l'énergie électrique produite en Europe sera d'origine nucléaire; pour l'essentiel à base de technologie à eau ordinaire d'origine américaine. D'autre part la consommation d'énergie électrique continuera certainement, pour toutes sortes de raisons, à augmenter plus rapidement que la consommation globale d'énergie, si bien que la part d'énergie primaire transitant par la voie électrique passera d'environ un quart aujourd'hui à la moitié à la fin du siècle.

Les problèmes relatifs aux nuisances réelles ("pollution" thermique, atteintes au paysage) ou potentielles (déchets, accidents) que pose la technologie nucléo-électrique ne sont, à mon avis, ni dirimants ni à l'opposé faciles à résoudre. Il faudra consacrer à leur solution beaucoup d'efforts et d'argent, éduquer l'opinion publique, prendre en compte les risques de toute espèces, y compris par exemple ceux de la guerilla. Mais tout cela n'est certainement pas hors de portée.

Par ailleurs, l'énergie nucléaire verra très probablement son extension atteindre des domaines industriel ou tertiaires nouveaux: les "hautes températures", l'utilisation des chaleurs "de rejet", l'utilisation de l'hydrogène comme moyen de transport, offrent des possibilités dont on ne peut encore évaluer la portée.

Dans le même temps, la surrégénération, dont la faisabilité technologique est démontrée et dont la rentabilité industrielle est à la veille de l'être, aura sans nul doute prouvé ses mérites. Si bien qu'au cours de la première moitié du XXI^e^ siècle, on peut prévoir que les problèmes énergétiques s'estomperont progressivement. A l'effet apporté par l'énergie nucléaire, s'ajouteront les réactions positives que la crise présente vient d'amorcer dans les autres secteurs, en particulier l'énergie solaire, l'énergie géothermique, voire l'énergie éolienne et quelques autres. Il sortirait très largement de mon propos d'entrer dans une

analyse de ces effets, ce d'autant plus qu'ils ont été abordés par d'autres auteurs au cours su présent colloque. Je me bornerai à leur sujet à une remarque assez générale:

Dans tous ces domaines, le problème fondamental est un problème de concentration: nous nous trouvons, en fait, devant des ressources énergétiques d'une extrême abondance, mais qui sont dispersées sur de très vastes surfaces, et par conséquent dont la captation exige de très importants investissements par Kw installé. On aperçoit une fois de plus cette évidence que ce qui est coûteux, c'est de concentrer quelque chose qui est dilué et qu'à l'inverse, l'utilisation d'une ressource, quelle qu'elle soit, a pour effet d'en organiser en quelque sorte la dilution. C'est un domaine dans lequel l'énergie parait en effet particulièrement exemplaire. On pourrait dire que l'énergie est présente partout, mais que le grand problème devant lequel nous nous trouvons placés est celui de sa concentration. Nous devons donc, par tous les moyens, éviter des dilutions inutiles, ce qui suppose, par exemple, une bonne isolation thermique des habitations et des locaux. D'autre part, il faut faire appel aux ressources les plus concentrées possible: c'est évidemment l'atome qui répond à cette définition.

CONCLUSION

L'énergie présente un certain nombre de caractères tout à fait spécifiques, le principal étant, me semble-t-il, que son importance est hors de proportion avec le faible pourcentage en valeur qu'elle représente dans l'ensemble des consommations de biens et services. Les énergies primaires représentaient dans le revenue national brut des pays industrialisés, avant la crise pétrolière, de 3 à 4% et si le chiffre a nettement augmenté, son ordre de grandeur n'est pas aujourd'hui différent.

Mais l'énergie se trouve en amont de presque toute activité. Il en résulte que la perspective de manquer d'énergie est particulièrement dramatique pour les sociétés industrialisées. Ce manque peut se produire de deux façons:

— Soit par épuisement des ressources naturelles et c'est à ce genre de souci qu'a répondu le rapport du Massachusetts Institute of Technology pour le club de Rome; nous pensons que cette crainte est complètement dénuée de fondement.
— Soit par une privation volontaire de la part des pays détenteurs des principales ressources; ces pays pourraient éventuellement les couper brusquement, mettant les nations industrialisées dans une situation temporairement très difficile. C'est un risque, nous l'avons vu, qui ne s'est pas concrétisé bien qu'il ait été l'objet d'une menace précise. La tendance générale des pays industrialisés au cours des dernières années, tendance qui semble aujourd'hui de nouveau reprendre une certaine force, parait être que ce genre d'évènement est trop grave pour pouvoir être envisagé. Naturellement une telle réponse n'est pas très satisfaisante, sur le plan de la responsabilité politique.

Il n'est pas douteux que l'énergie a constitué pour l'humanité à la fois une condition nécessaire de la croissance économique et un moteur dans la mesure où l'abaissement progressif de son coût au cours des siècles a encouragé une utilisation de plus en plus abondante d'esclaves mécaniques. Mais il est peut être intéressant aussi de constater

que l'énergie a été dans beaucoup de domaines un révélateur des grands problèmes de l'humanité:

— Evolution sociale et politique au XIX^e et au début du XX^e siècles.
— Opposition entre nations développées et nations détentrices des matières premières utilisées par celles-ci.
— Contradiction dans les réactions occidentales en ce qui concerne la façon de traiter les dits pays.
— Problèmes de l'écologie dont je n'ai presque pas parlé, mais qui, bien sûr, ont été particulièrement mis en évidence dans le domaine de la pollution atmosphérique, engendrée par la production et l'utilisation de l'énergie.
— Et enfin, peut-être les problèmes de l'énergie ont-ils joué un rôle important sinon dans la naissance de la futurologie, du moins dans la place qu'elle a pu prendre dans nos réflexions.

Mais en ce qui concerne le grand avenir, à deux ou trois générations d'ici, il semble bien que nous sommes maintenant en mesure de régler les problèmes que nous posent l'alimentation en énergie de nos économies. Certes il sera tout à fait raisonnable de tenter d'apporter quelque modération à la croissance de nos besoins d'une part et quelque imagination pour utiliser du mieux possible les ressources renouvelables, et tout particulièrement l'énergie solaire.

Il reste que l'électricité prendra une part croissante dans l'énergie utilisée par l'industrie et les ménages, et que, grâce à la surrégénération, le problème de la production d'électricité peut être considéré comme résolu. L'atome aussi pourra sans aucun doute se tailler de nouvelles applications notamment dans l'industrie grâce aux hautes températures. Enfin tout permet de prévoir que l'amélioration de la technologie réglera de façon satisfaisante le problème des rejets thermiques en diminuant l'ampleur, ainsi que les questions relatives à l'utilisation des sous-produits de la fission. De sorte que l'on peut prévoir, à l'échéance considérée, que les problèmes de l'énergie auront singulièrement perdu de leur importance, sinon de leur intérêt.

Cela s'explique aisément: nous sommes, en effet, dans le domaine énergétique ou du moins nous étions jusqu'à l'apparition de l'atome devant des problèmes fondamentalement quantitatifs. Il s'agissait d'avoir de la matière, de la puissance, pour remplacer les esclaves et assurer les approvisionnements de notre développement socio-industriel. Désormais, nous sommes devant des problèmes non plus quantitatifs, mais technologiques et tout permet de penser que nous sommes en mesure de les résoudre. Lorsque nous aurons notre content d'aides mécaniques, et à condition de ne pas abuser, bien d'autres domaines apparemment plus vastes et probablement plus intéressants appelleront l'attention des générations futures: on pense aux développements dont on prévoit à peine les prodigieuses possibilités de l'informatique; on pense à la biologie qui présente ce caractère étonnant de changer de dimension presque à chaque décennie. Et peut-être (pourquoi pas?) peut-on penser à la remise en ordre de la gestion de nos affaires à l'échelon de la planète. N'est-ce pas ce dont nous semblons avoir le plus besoin? Et ne peut-on espérer que la politique deviendra non pas certes une science exacte, mais un sujet de réflexion rationnelle en vue d'applications paisibles?

DISCUSSION

JASKE: I would like to continue along the lines that Mr. Otte started. I think that Prof. Nordhaus and his fellow economists have created a whole fictitious world that is more of an academic exercise than anything that is realistic. I think the basic reasons—in my own investigations—spring from the fact that economists apparently have completely failed to make an honest effort to evaluate the past performance of their own economic projections. They have failed completely to evaluate the transition from capital financing to debt financing and its effect on the ability to organize the enterprise of the country. In my view, economic theory has produced absolutely nothing of value in the last 20 years to help in the question of internalizing costs which are not at all taken care of in some of these exercises that we've had described to us. I cite, for example, the Columbia River power system which to this day is still based in part on 2% interest, 75-year rolling depreciation, all kinds of economic gimmickery which in no way reflects the true value of electricity. It's simply an institutionalized price. From this basis, then, all manner of optimizations spring forth which justify income redistribution schemes and political activity, none of which appear to me to really reflect on the basic problem that I feel is as important. If economists would look backward a little bit better, an attempt to criticize themselves a little more thoroughly in terms of attempting—even as the political scientists are trying to do—to model the game plans of the past, I think we would be a lot further ahead. I'm really very tired of regression projections and the whole battery of fictitious techniques which economists employ. One of my good associates, Dr. Landsberg, with the Resources of the Future, made perhaps the best energy forecast of any that has been made in the United States. Yet I find that his own analysis of the reasons for error, which he believes, are amazingly short-sighted in terms of his explanation as to why he was 400% off on the growth of electricity in commercial buildings. It's this kind of gross lack of appreciation of the technical factors and the lack of apparent knowledge of the feedback relations that ensue from economic theories and income redistribution theories that are causing a great deal of our difficulty. I cite again another terrible example in my view. The fact that in the United States we have had a total regression in efficiency of electrical energy production to the point where these last two years we have had our average plants down below what they were traditionally, and as long as we depend on light water nuclear reactors, I see no way in the foreseeable future that we can ever get back to any kind of talk about efficient use of energy under the present circumstances. Technically, cheap energy has crippled and subverted the development of engineering of efficient structures and efficient uses. In 1952 we had triple reheat boilers; we had super critical steam plants; we were talking about 1200°F super heat. Today, a standard fossil plant is 1050°F, single reheat, "blow it out the stack" plant about 5% less efficient than we had in 1950. In my view banking and commercial interests have so monopolized the thinking in this whole area that they really haven't left any room for honest, efficient use of anything to prevail.

RANDERS: Thank you, Mr. Jaske. I don't know if Mr. Nordhaus wants to reply, or should we perhaps take another couple of remarks, and come back to this harsh judgment of the economists?

LEWIS: I hope the two economists or industrial practitioners who have just spoken will be able to stay for my paper because I can promise them something different.

RANDERS: This was a preview of coming events.

BLACKSHEAR: Walter Heller, at the time of the beginning of the oil shortage, suggested that we bank some of the increased cost for immediate use in promoting research on alternative sources of energy, part of the increased tax be used to reduce the regressive effects of the tax, and then part of it simply be used to clean up the environmental impact of the uses of energy. When you started out on your concluding remarks you suggested that we should breeze through the cheap energy very fast, and use the money we save to bank against developing alternative sources. But your final remarks seem to contradict that in that you felt that we really had too much energy and that the environment couldn't stand it. I was left somewhat confused. I sort of liked Heller's scheme initially, and I wonder if you could comment on how your idea of rushing through cheap energy in a hurry compares with a taxation scheme for immediate research on alternative sources?

NORDHAUS: I'll respond to the last speaker and the last speech. Coming first to your question, in Heller's remarks—and this was about 8 months ago—it was the consideration of having a tax scheme during the embargo, to help close the gap between the supply and demand. This would raise a certain amount of revenue and the question was, What would happen to the revenue? His scheme was a way of essentially spending the money so that you wouldn't have too much depression of the demand overall. I personally didn't think it was a great scheme, but a very different scheme, and for my point of view a rather bad one,

from the long run R & D support for energy in general. The reason it's probably a bad scheme is because when the embargo fell apart the tax would have fallen apart and R & D support probably would also have fallen apart. I think for that reason it was not a terribly good idea.

Let me just clarify on the apparent confusion that I have sown here. I was trying to speak slightly paradoxically when I said that perhaps the problem is too much rather than too little. I'm trying to put this in the context of the kinds of questions that this conference is designed to investigate, whether overall availability of energy resources place limitations on world economic growth, that insufficient energy is *not* the chief problem. If anything is going to be the problem, it's that too much energy will be used. As for the gentleman in the front, I'm not sure what that speech was written for. I'm not sure whether it was written for this session or another one; the blanket denunciation of economists, politicians, the army, financiers, bankers, and everyone except honest engineers. I think that any profession can make that same complaint. But I must admit that I really didn't get the point as to what that had to do with the energy problem.

RANDERS: As for too much or too little energy, what I understand you to mean is that we are using too much energy and not that we have got too much energy?

NORDHAUS: Yes, that's right.

BLACKSHEAR: I didn't quite get the point clarified. It would seem to me that an abundance of inexpensive energy would have an effect of encouraging energy use so that something else ought to be done. If it is affecting the environment, that means that there is something we have not internalized. Is this an omission in your model? Didn't you include the environmental impact which you felt that the rapid use of energy caused?

NORDHAUS: There are some problems, obviously, which economic models of this kind can handle, and for others it is very difficult to include them in economic models of this kind. I mentioned three of them. It is difficult to include the problem of nuclear waste disposal other than by saying what would it be worth to have or not to have the nuclear options, what is it going to cost to throw it out altogether? The other two problems actually are problems that you could handle. For example, a particular problem which has concerned these meetings is the problem of the thermal waste in the aggregate not localised. To modify models you could impose a constraint on this world economic system that you shouldn't consume more than some fraction of solar energy (say one-tenth of 1%, or 0.5 of 1%). This reshapes the pattern of utilization; you will speed it up in the early stages before you hit the ceiling, and then obviously it would be dead stop in the rate of growth once you hit the ceiling. The general effect of this kind of constraint would be that energy resources are less valuable because at some point in the not too distant future you will be unable to use them as rapidly as you'd like to. So that, in general, imposing constraints—either the CO_2 kind or the kind of the general heat balance—would tilt the efficient allocation toward more early use and less late use because of the fact that you're hitting the ceiling sometime later in your time pattern.

THE IMPACT OF NUCLEAR ENERGY ON SOCIETY, POLITICS, AND ECONOMICS

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For the world the basic purpose of harnessing nuclear energy was and should still be to overcome the deprivation and near starvation that now afflicts a major part of its population. Moreover, the population is still increasing, but most agree the rate of growth must be reduced to keep the total below some limit, probably below 20 000 million. However, even some learned scientists who should know better not only shun but even oppose the harnessing of nuclear energy to meet the world's needs. Very many suggest that ultimately man will harness solar energy for his needs. One book of 1952 carrying this idea is by Sir Sir Charles Galton Darwin called *The Next Million Years.*[1] After discussing the various sources of harnessed energy, he concludes on page 75: "Of all the possible ways of collecting energy, the direct use of sunlight is the most promising." He does not, however, make the mistake of supposing this would give a high standard of living; p. 189: "It is quite safe to say that there will always be rich and poor . . . (for the poor) the standard of living of any community living on its real earnings, as the communities of the future will have to do, is inevitably lower than that of one rapidly spending the savings of hundreds of millions of years as we are doing now." Sadly the author is not alive today to hear me point out that already we need no scientific breakthrough to head towards a standard of living that is far higher for the average and even relatively more for the poor than has ever been known. The umbrella relation $E = mc^2$ is most generous with energy.

Let me state as a goal a per capita supply of harnessed energy averaged for the whole population at five times that now consumed per capita in North America which is ten times the world average and for a world population four times the present number.

I will show that the harnessed energy supply can double every 10 years. To achieve the total increase of 200 times would at that rate take less than 77 years, that is only to the end of the year 2050. Let us hope, however, that the world population will not be quite so high so soon. It would then not be necessary to maintain quite so short a doubling time towards the end. For a slightly longer doubling time a higher standard of living can be sustained.

I sincerely believe that what I have said is quite true. I realize, however, this must come as a severe shock to many of you who believed otherwise, so in the few minutes left to me I must help you to understand. I have said no new technical breakthrough is needed: that includes no commercial fast breeders, no thermonuclear fusion; but they would be welcome

if they meet the economic competition. Sudden disruptions of men's activities must be avoided because they are costly. Changes of thinking, motivation, and changes of aim, however, are to be accepted and may be necessary. For individuals there may be disruptions; some unemployed will find work; some workers will find different work. There will be new work in processing radioactive materials, but no changes seem necessary in radiation protective standards. Nuclear war must continue to be avoided as it has been, but greater political security would be welcomed.

I base my belief on the established performance of the Pickering Nuclear Generating Station of Ontario Hydro. This station has four CANDU reactors with heavy water moderator and caloporteur and natural uranium oxide fuel. Zirconium alloys are used for the fuel cladding and the fuel channel tubes. Each reactor has a gross generating capacity of 540 MWe and the net station output is 2056 MWe, that is a little over 2 million kW. In 1973 it was the highest power commercial nuclear generating station in the known world, but others are comparable. Its availability has been outstanding, and in 1973 it delivered 14×10^9 kWh, which was 40% more than its nearest rivals and despite the fact that the fourth unit was only put into service towards the end of May.[2] Fuel is changed with the reactor on power. The fourth unit reached full power only 12 days after startup. The cost of energy generated is fully competitive in the Ontario Hydro system and less than some water power; it was evaluated as 6.2 m (1972) $/kWh at the end of 1972.[3] I will discuss this in more detail later.

The key to this success and promise is the fuel bundle (Fig. 1). One single bundle such as this containing about 20 kg of natural uranium yields as much power as 560 tons of the best coal. Moreover, at the end of the irradiation it looks the same but, of course, is highly radioactive; but all the radioactive fission products, including krypton, iodine, and tritium, are firmly held within the sheath in each of the 28 rods in the bundle. The whole bundle can be safely stored under water for at least several decades. A rupture of the sheath is now very rare, only one rod had a leak in more than 5000 spent fuel bundles.[4] No release to the environment need result.

Note that the energy obtained corresponds to 28 000 times that obtainable by burning the same weight of coal. Moreover, the total fuelling cost for a given amount of energy is less than one-fifth of that for coal at a similar coal-fired station in the same area.[3] It is also less than half of the fuelling cost of any other type of commercial nuclear power reactor.[5] This has great importance for the suggested large scale use.

Table 1 is prepared from a 556 page book[6] entitled *Energy in the Future* by Palmer C. Putnam, published in 1953. The book resulted from a worldwide study with contributions from many countries sponsored by the USAEC in 1949–53. From the point of view of a hypothetical trustee of world energy, Mr. Putnam asks how much he can prudently count upon for the 100 years from 1950 to 2050, from various sources of energy subject to a limit on cost of twice that from coal in 1950. He postulates as plausible a population of 8000 million in 2050, which now seems low, and estimates the cumulative demand for energy as 72 to 487 Q. (My suggestion above of 50 kW per capita for 15 000 million population by 2050 reached by doubling the harnessed energy every 10 years corresponds to a cumulative total of 333 Q from now to the end of 2050.) Mr. Putnam saw the popularity of the fluid hydrocarbon fuels rising until the cost in about 1975 became so high that synthetic fluid hydrocarbons would begin to compete, a remarkably accurate projection. He, however, charges up to coal the necessary energy loss in the synthesis, whereas now we can see this coming more cheaply from nuclear energy.[7]

Note his conclusion that the fossil fuel sources could provide 27 Q but the income or renewable sources could only be counted on for 5–10 Q. Moreover, this was a well-informed opinion. Mr. Putnam himself was an engineer consulting in solar energy; he had been responsible for the highest power, windmill or air turbine rated at 1.25 MW that operated on Grandpa's Knob in Vermont until it broke in 1945.[8] He assigns a build-up of wind power units to a total of 200 MkW by 2050, but the integrated contribution would be only 0.1 Q. Recently Prof. W. E. Heronemus has suggested a larger contribution,[9] but I suspect that even a million 200 kW units would rather spoil the landscape or seascape for aesthetic environmentalists, and whether the world builds them or not would not make much difference to finding the needed 72–333 Q.

Mr. Putnam thought it prudent to look for at least 31 Q from nuclear fission if that could meet the cost target. Canada's recent experience shows that the cost can be less even than the cost from coal in 1950 in terms of constant dollar values.[10]

TABLE 1. Harnessed world energy
100 year cumulative inputs to 2050 at real costs not above twice 1950 costs

Income sources	Q	Fossil sources (adjusted for synthesis losses)	Q
Solar heat collectors (space heating, water heating, midday cooking, etc.)	5	Coal	21
Fuel wood	1.4	Natural oil and gas	5
Farm wastes	1.0	Oil shale	1.0
Water power	0.6	Tar sands	0.2
Wind power (to 200 MkW)	0.1		
Solar power collectors	0.05		
Geothermal, tides, etc.	0.076		
Total	8.226 Q		27.2 Q
Take	5 to 10 Q		
Nuclear energy (min. plausible)	35 Q (437 500 Te. fiss. Th + U +Pu)		
Grand total	67–72 Q		
Plausible demand	72–487 Q		

I have said we can manage to double the energy supply every 10 years. As evidence for this, Fig. 2 shows how Ontario Hydro managed to meet a demand increasing at rather more than that rate since 1948 at a unit energy cost to its customers that did not increase in constant dollar values. Figure 2 also shows that the cost of energy from Pickering fits quite well into the system. Ontario Hydro does not lose money and it has operated as an isolated public cooperative. The basic economics of the method is available to all in industrially developed states[11] to achieve that 200-fold expansion in 77 years with CANDU.

Moreover, the push and pull of economics will bring about some changes from the Pickering type of CANDU reactor. Perhaps the most important change will be to use thorium oxide fuel with recycled uranium-233. The push towards this change will come from the increasing cost of natural uranium, the pull will come from the prospect of much less frequent fuel changing and a reactor so compact that the same size unit, or one even somewhat smaller, could generate 1500 MWe instead of 540 MWe. Moreover, by using the organic liquid caloporteur HB-40 already successfully employed in the 50 MWt experimental reactor WR-1 in Manitoba, the thermal efficiency can be increased to 38 or 39%.[12]

Experience with the HB-40 caloporteur has shown other highly significant advantages, especially the insignificant radiation levels from the primary circulating pumps and piping. It has been possible to work without radiation shielding close to the pumps with the reactor at full power, and when a bearing was changed no radioactive decontamination or shielding was necessary. The ease of maintenance operations will acquire great significance when nuclear energy is generated throughout the world on the much larger scale in prospect.

I must now return to the fears expressed that there may be accidents and sabotage on a significant scale encouraged by the awesome potential of nuclear explosions and even of

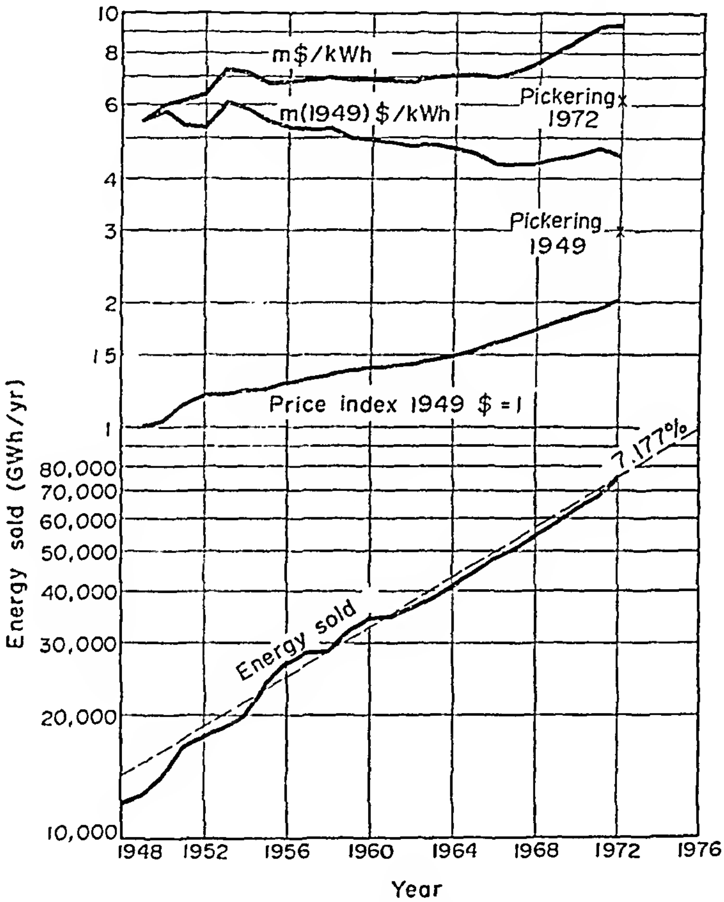

Fig. 2. Ontario Hydro statistics, 1948–72.

nuclear radiations from the fissile materials such as plutonium and the fission products. I am not suggesting that the cost of teaching future generations to behave rationally is going to be small, but the benefit of abundant harnessed energy to raise the standard of living of the deprived and starved tens of millions is surely much greater.

Concerning the biological effects of radiation and the stimulated fear of plutonium, I have several times written straightforwardly.(13) Generally there has been no response, but what response there has been was abusive. Today I will tackle this indirectly by quoting the following vision from world literature: "Violence is invariably interwoven with THE LIE. And as soon as the lie is dispelled, the repulsive nakedness of violence is exposed, and violence will collapse in impotence. 'One word of truth outweighs the whole world'."(14)

To which I will add Science has become entangled, first with the BOMB and now with the LIE. Let us listen intently for that word of truth and join in the task of exposing the lie, to halt the twentieth century before it outshames its record of Belsen and Auschwitz, by neglecting the deprived and starved tens of millions, through withholding confidence from those capable of bringing abundant harnessed nuclear fission energy to their help at low cost and low risk.

EXCERPTS FROM MY LECTURE IN VIENNA IN DECEMBER 1971 AS PUBLISHED IN *IAEA BULLETIN* Vol. 14, No. 4, SEPT. 1972

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Science has not yet established whether the background level of radiation in the world is good or bad for human life; it could even be essential. Most probably it is beneficial to the majority but detrimental to some. In case you think otherwise, let me remind you of something somewhat analogous that is quite standard in pathology, namely, the effect of sunlight on the skin. Men, especially white men, who habitually work with their skin exposed to sunlight, become liable to develop skin cancer. Yet sunbathing is popular and indeed a limited exposure is beneficial in producing vitamin D required for calcium and phosphorus absorption in bone metabolism, although in rare cases a cancer may develop.

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Too many people are not aware of the current science of radiation effects in living organisms. I will quote from the opening paragraphs of the foreword to the Proceedings of an IAEA panel in Vienna in 1966 on "Genetical Aspects of Radiosensitivity: Mechanisms of Repair": "Recent biological and biochemical observations in radiation research have brought about marked advances on the simple, non-biological interpretation held less than a generation ago. Then, the effects of radiation exposure on living systems were viewed as being direct, immediate, irreparable and unmodifiable. Now, it is generally accepted that radiation injury can also be indirect, delayed, reparable and often modified with appropriate radioprotective measures. One of the most exciting developments to emerge recently from the multidisciplinary approach to radiobiology is the concept of repair, whereby the observable damage is the net balance of the initial lesions minus the repaired ones."

Let me remind you of one more basic idea in biology. Living cells grow and multiply by feeding on their surroundings. The food does not have to be specific but in the metabolic processes a wide range of compounds are first broken down to simple chemical molecules or radicals and then built up to fit the need. Thermal and chemical disruption called pyrolysis and hydrolysis take part and background radiation provides photolysis and radiolysis as well. There exists an optimum range of temperatures, of hydration and probably also of radiation for these processes, and for their opposites, for example "photosynthesis".

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Current and prospective energy costs

Type of station			Pickering		4 × 1500 MWe CANDU-OC-Th
(Note H = 8766 h/yr; M = 10^6)			Official	Optimistic	Optimistic
Station capacity	S	MWe (net)	2056	2056	6000
Capital cost	C	M$	746	657.92	1200
Specific cap. cost	1000 C/S	$/kWe	362.84	320	200
Capacity factor	u	%	80	90	90
Fixed charge rate	A	%/yr	8.88	7.8	7.8
Net station effy.	e	%	29.1	29.1	39
Fuel unit cost (net)	P	$/kgU (or H.E.)	50.7	45	187
Burn-up (thermal)	B	MWd/kgU ,,	8.291	8.291	33.3
Annual costs					
Fixed charges	CA	M$/yr	66.25	51.32	93.6
Operating and maint.	N	,,	7.83	7.83	16.58
Heavy water upkeep	D	,,	2.84	1.70	0.95
Fuelling	HuSP/24MBe	,,	12.64	12.61	28.40
Total		M$/yr	89.55	73.46	139.53
		M(1949) $/yr	44.11	36.19	68.73
Unit energy cost					
Capital	MCA/HuS	m$/kWh	4.60	3.16	1.98
Operating and maint.	MN/HuS	,,	0.54	0.48	0.35
Heavy water upkeep	MD/HuS	,,	0.20	0.11	0.02
Fuel	P/24Be	,,	0.88	0.78	0.60
Total		m$/kWh	6.22	4.53	2.95
		m(1949) $/kWh	3.06	2.23	1.45

AMELIORER LA VIE EN ECONOMISANT L'ENERGIE (BETTER LIFE THROUGH LESS ENERGY)

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ENERGIE ET CIVILISATION

Un des thèmes proposés à notre Conférence est d'étudier "les économies d'éner possibles qui n'affecteraient pas la qualité de la vie". Je voudrais aller plus loin dans ce direction et indiquer que certaines économies d'énergie pourraient avoir pour résul d'*améliorer* la qualité de la vie et d'enrichir la civilisation.

Dans toutes les discussions sur la crise de l'énergie on semble accepter comme une vér évidente que l'augmentation de la consommation d'énergie per capita a facilité le dévelop ment de la civilisation et a rendu la vie plus agréable. Sans vouloir-être iconoclaste ni mê sceptique quant aux bienfaits de l'énergie, il me semble qu'il serait utile d'examiner ce opinion, car elle est au centre de nos débats. Dans le titre de la Conférence "Les ressour énergétiques à long terme et la croissance" le mot croissance ne doit certainement pas ê pris dans un sens purement économique et technologique. Tous les bons esprits rejette maintenant cette étroite interprétation du mot. Il s'agit donc de mieux définir le rôle c ressources énergétiques dans nos sociétés. Pour illustrer que le mot croissance doit co porter des valeurs humaines qui transcendent l'économie et la technologie, je poserai so une forme élémentaire deux simples questions qui révèlent combien nous sommes ignora des rapports qui existent entre la consommation d'énergie et la qualité de la vie.

La consommation moyenne d'énergie per capita aux Etats Unis est à l'heure actuelle peu près le double de ce qu'elle est en Europe. De quelle façon cela contribue-t-il à rend la civilisation américaine supérieure à l'européenne? ou a lui permettre de se dévelop plus rapidement dans une direction désirable? Faut-il en conclure de cette plus gran consommation que les Américains sont en moyenne plus heureux que les Européens?

Aux Etats-Unis, la consommation d'énergie per capita est aujourd'hui le double de qu'elle était il y a trente ans. Dans quelle mesure la civilisation américaine a-t-elle é rendue meilleure par cette augmentation? L'Américain est-il maintenant plus heureux, simplement moins malheureux, qu'il ne l'était il y a trente ans?

Ces questions ne mériteraient pas d'être posées puisqu'elles n'offrent pas de possibilit de réponses, si ce n'était qu'on accepte tacitement à leur égard des attitudes qui sont vides sens ou qui mènent à des confusions. En 1971, un illustre professeur du IT pren la défense des surrégénérateurs en affirmant d'une façon péremptoire

abondante d'électricité ... est essentielle à la civilisation." Il me semble utile de donner ici la phrase anglaise elle-même: "An abundant supply of electricity . . . is essential to civilised society." Ce professeur savait naturellement que beaucoup de sociétés ont atteint un haut degré de civilisation et de bonheur bien avant l'utilisation de l'électricité, mais il faisait allusion au fait que l'électricité est essentielle à nos formes présentes de civilisation industrielle. Le professeur voulait donc vraiment dire que l'électricité est essentielle—non pas à la civilisation—mais aux sociétés qui mesurent leur succès par les productions et formes d'activité que facilite l'électricité. Cet argument circulaire semble anodin mais est dangereux parce qu'il empêche de se poser de vraies questions quant aux effets de la consommation d'énergie sur la qualité de la vie.

L'avenir serait sombre s'il était vrai que la qualité de la vie dans les sociétés industrielles dépend étroitement de l'abondance de l'électricité. Car l'expérience montre que plus nous en utilisons, plus nos besoins énergétiques augmentent et plus graves deviennent les problèmes technologiques et sociaux que posent non seulement la production, mais encore plus l'utilisation de l'énergie. Heureusement, on a commencé à reconnaitre, et dans certains cas à démontrer scientifiquement, qu'une diminution dans l'usage de l'énergie pourrait avoir des conséquences favorables pour les humains, pour leurs sociétés, pour la Terre—en d'autres termes pour la qualité de la vie. Je me limiterai à quelques exemples touchant à la santé physique et psychique, à l'architecture et la planification, à la production agricole et la qualité du paysage.

ENERGIE ET SANTE

Dans tous les pays où l'énergie est abondante et où la richesse économique est généralisée, un très grand pourcentage de la population en profite naturellement pour éviter les efforts physiques et pour avoir une alimentation plus abondante et plus riche. Les Américains par exemple consomment en moyenne quelque 3500 calories par jour dont un grand pourcentage vient de matières grasses animales, et du sucre, alors que certains autres peuples qui ont un travail physique plus long et plus pénible ne consomment que 2000 calories dont une grande partie vient de substances amylacées.

L'expérience clinique, les études épidémiologiques et les recherches de laboratoire s'accordent sur le fait qu'en général la santé et la longévité bénéficient d'une alimentation plutôt frugale et d'un effort physique et mental vigoureux qui se continue à un rythme plus ou moins régulier tout le long de la vie. De ce point de vue, il n'est pas sans intérêt de rappeler que les pays où les vieillards retiennent leur vigueur le plus longtemps et où le pourcentage de centenaires est le plus élevé, sont ceux où la consommation de nourriture est assez restreinte et où les habitants doivent se livrer à un travail physique continu pour survivre. Dans nos pays une économie d'énergie pourrait facilement s'obtenir en diminuant la consommation de matières grasses et de sucre, et en dépendant moins des machines pour les déplacements et les travaux dans la vie quotidienne. Il est probable qu'un tel changement dans les modes de vie diminuerait la fréquence et gravité de certaines des maladies organiques, qui sont dites maladies de civilisation parce qu'elles ont beaucoup augmenté dans les pays industriels.

La vie psychique aussi souffre probablement du fait que l'utilisation de l'énergie dans la plupart des activités de la vie quotidienne diminue de mille façons les contacts avec la réalité. En général, nous ne pouvons jouir complètement d'une expérience que dans la

Fig. 1. Pickering fuel bundle.

mesure où nous y participons d'un façon active, par un effort physique et mental. Toute expérience passive est affaiblie et déformée.

"Energy is Eternal Delight" ... "Energy is the only life and is from the body" écrit William Blake. Cette énergie dont il dit qu'elle est une source éternelle de délices vient non du dehors mais de la vie et du corps. En principe, l'énergie qui vient du dehors pourrait servir à augmenter et diversifier nos contacts avec le monde extérieur; mais en pratique la façon dont on l'utilise appauvrit ou même élimine ces contacts, pour les remplacer par des expériences indirectes qui sont atténuées et généralement déformées.

ENERGIE ET ARCHITECTURE

Dans le passé l'architecte et le planificateur étaient presque esclaves des conditions locales telles que la topographie, la nature du sol, l'abondance de l'insolation, de la pluie et de la neige, la nature des matériaux de construction dont on disposait. La nécessité de tenir compte de ces contraintes mettait les styles d'architecture et de vie en correspondance intime avec les conditions locales. Il s'est ainsi développé au cours des siècles dans chaque région une "architecture sans architectes" dont la justesse se manifestait non seulement par l'économie de construction et d'opération, mais aussi souvent par le confort et par le charme régional.

Grâce à l'abondance de l'énergie et à ses facilités d'utilisation, architectes et planificateurs sont maintenant presque indépendants des contraintes locales. Il ne leur est plus nécessaire d'adapter leurs plans à l'intensité du soleil ou du froid, à la quantité de pluie ou de neige, à la proximité entre lieux d'habitation, de travail et d'approvisionnement. L'utilisation de l'énergie sous une forme ou une autre leur permet de protéger le public des intempéries et de le déplacer presque sans efforts même sur de longues distances.

La méthode qui consiste à résoudre les problèmes architecturaux et de planification par une utilisation extravagante d'énergie est en réalité une méthode paresseuse et qui présente de nombreuses objections. Elle est d'abord très coûteuse et le deviendra de plus en plus au fur et à mesure que le prix de l'énergie augmentera. Elle mène à une banale standardisation et à une multiplication de demeures anonymes qui détruit la qualité des paysages ainsi que la personnalité et le charme des styles régionaux. Enfin elle désorganise la société en rendant la vie de voisinage de plus en plus difficile, et de moins en moins intime.

Si l'énergie venait à faire défaut ou à devenir vraiment coûteuse, on verrait sans doute renaître une architecture et une planification mieux adaptées aux conditions locales. Il en ressortirait des styles plus intéressants et plus variés, et sans doute aussi des conditions de vie qui faciliteraient les contacts humains et favoriseraient ainsi la renaissance de l'esprit de communauté.

ENERGIE ET AGRICULTURE

La productivité phénoménale de l'agriculture moderne implique un emploi intensif d'un outillage très complexe, d'engrais chimiques, d'herbicides, d'insecticides et souvent de l'irrigation. Son efficacité ne doit donc pas se mesurer uniquement en termes de quantité totale de production. Il faut aussi tenir compte de la quantité d'énergie requise par unité de production. Et quand on la juge sur cette base, l'efficacité des pratiques agricoles modernes est souvent très faible. Le fermier moderne dépense beaucoup plus de calories "industrielles"

qu'il ne recueille de calories "alimentaires" sous forme de nourriture. Ses dépenses énergétiques consistent par exemple en carburant pour faire fonctionner ses tracteurs, ses camions et autre équipement, en électricité pour produire engrais et pesticides, en toutes les formes d'énergie requises pour la fabrication de son outillage et pour l'irrigation.

En général, plus l'agriculture dépend de l'énergie industrielle, plus son vrai rendement diminue si on le mesure en termes de quantité de calories utilisées pour la production d'une quantité donnée de nourriture ou de textiles. De ce point de vue, l'agriculteur moderne avec son outillage industriel a des rendements beaucoup plus faibles que n'avait le vieux paysan avec son attelage de bœufs. La différence de rendement est vraiment énorme si l'on en croit des calculs très récents de coût énergétique. Alors que dans certaines cultures "primitives" pour une calorie investie (surtout en travail musculaire) on obtient 5 à 50 calories alimentaires, sans nos pays développés il faut 5 à 10 calories de combustibles fossiles pour produire 1 calorie de nourriture.

Il est superflu de dire que nos formes de civilisation seraient inconcevables si l'énergie maintenant requise par l'agriculture devait être fournie par la force musculaire. Mais il est très probable d'autre part que le *coût* de l'énergie orientera l'agriculture de l'avenir vers l'emploi de méthodes avec un rendement énergetique plus élevé. On peut prévoir que ces méthodes auront pour idéal une adaptation plus parfaite entre les forces naturelles locales et la production agricole. On peut imaginer par exemple des pratiques favorisant les microbes du sol fixateurs de l'azote atmosphérique ce qui diminuerait le besoin en fertilisants azotés; l'association de plusieurs espèces de plantes pour obtenir une photosynthèse plus effective; des regroupements de haies vives qui, sans empêcher l'emploi de l'outillage agricole moderne, augmenteraient la variété écologique et par là l'efficacité de la lutte contre les parasites; des conditions de culture et d'élevage qui encourageraient l'accumulation de l'humus dans le sol. C'est par de tels procédés que, d'une façon largement empirique, les anciens paysans maintenaient la fertilité de leur terroirs, génération après génération. Il est possible d'imaginer une nouvelle révolution agricole, qui supplémenterait les pratiques basées sur l'utilisation de l'énergie, par des méthodes d'un ordre plus biologique et écologique.

Une agriculture utilisant moins d'énergie et plus respectueuse des nécessités écologiques aurait sans doute l'avantage indirect d'augmenter le charme des paysages et leur individualité, en assurant une meilleure adaptation des terres et des méthodes au climat, au relief et autres caractéristiques de chaque région.

ENERGIE ET ADAPTATION

La façon la plus certaine d'étendre les bienfaits de l'énergie est de ne l'utiliser qu'à bon escient. Or il est certain que beaucoup de ses applications actuelles n'ont pas d'effets bénéfiques réels et tendent même à diminuer la qualité de la vie en menant la civilisation sur une mauvaise route.

Les exemples que j'ai cités pour illustrer cette thèse ont été choisis parce qu'ils ont tous un aspect commun. Ils correspondent à des situations où l'énergie n'est pas employée dans un but vraiment créateur, mais seulement pour diminuer les efforts que tout organisme—individu, société, ou écosystème—doit faire pour s'adapter aux conditions dans lesquelles il fonctionne. Cette tendance à remplacer les mécanismes naturels d'adaptation par un apport d'énergie du dehors a été menée jusqu'à un point d'absurdité dans le monde moderne—avec des effets qui sont non seulement négatifs, mais souvent destructeurs. Elle atrophie

les facultés physiques et mentales de l'humanité, elle appauvrit l'architecture et la planification en ignorant l'originalité qui vient de l'esprit du lieu; elle empêche les forces créatrices de la Terre de maintenir spontanément la fertilité, la variété écologique, et l'originalité des paysages régionaux.

Personne ne doute des bienfaits qu'une abondance d'énergie apporte à l'humanité. Il ne s'agit donc pas d'en limiter les effets bénéfiques mais au contraire de les augmenter, en l'utilisant pour élargir le champ d'action et la richesse d'expression des facultés humaines et des forces naturelles.

En adaptant les modes de vie, l'architecture, la planification, l'agriculture aux caractéristiques naturelles de chaque région, il sera possible non seulement d'économiser de l'énergie mais en même temps d'améliorer la vie et de stimuler la civilisation. D'une façon plus générale, on peut entrevoir qu'une utilisation plus économique de l'énergie contribuera à la qualité de la vie en permettant aux facultés humaines et aux forces naturelles de tirer mieux parti du milieu et d'établir avec lui des relations plus harmonieuses.

DISCUSSION

RANDERS: Thank you very much, Prof. Dubos. Your thoughts formed a very suitable and fine ending for this session here. Philosophy is probably as useful as technology when it comes to our worries about energy production and energy uses. Now we still have a little time for questions or remarks.

LAWAND: I'd like to address a question to Dr. Lewis. Yesterday I posed a question to Dr. Zraket about the net efficiency of nuclear plants in the United States and I would like him to give me an answer on that with regards to the CANDU (Canadian Government) reactors. That's question 1. Question 2: it was interesting to see that the figures on the board—perhaps I can just flip them over—I don't remember exactly what date Pickering was established and made operational. I'm quite interested to see the cost figures. But I'm also interested in some comments on the stability of this figure. In other words, based on your experience with other nuclear reactors, do you expect this type of figure to hold up? I was at a conference recently in the United States where there was quite a bit of criticism of the fact that some cost figures had been quoted on some nuclear plants which looked very optimistic at one time, but two or three years later the costs were no longer the same and they were quite substantially different and very much higher. I would like to get some information on both those points.

LEWIS: There were really several points there. One thing of course you might notice in the last line on the chart there was that which quoted 6.2 milli (1972) dollars. The trouble is that we are in a period of very rapid inflation and it is therefore necessary to specify what year you're speaking of in quoting any dollar value. That figure was for Pickering for 1972. We have now completed 1973 and the figure, on the same basis, is 6.6 milli (1973) dollars per kilowatt hour. So in a way one can say it's stable. On the question of when Pickering was commissioned, it was commissioned according to a program of one reactor, followed by another, followed by another, etc., until all four units were in use. I mentioned in the talk that the fourth unit was only commissioned at the end of May in 1973. So that in quoting that 14 000 million kWh in 1973, that represents a capacity factor of more than 80% during the time that the units were all operating. I think we can expect to go quite a bit higher than 80% utilization. Whether it will be possible to achieve 90%, I think is a bit in doubt. What has happened to that program? I thought some previous comments might be of interest; I have a paper here given by Mr. Woodhead, of Ontario Hydro, to the Canadian Nuclear Association in June this year, just citing what he was expecting to have to operate. He said: "In 1973, Ontario Hydro total installed capacity was 16 000 MW of which 2290 or 14% was nuclear. The nuclear units provided about 18% of the total electric energy in 1973. Ten years from now the total capacity will be 32 000 MW of which 13 000 or 41% will be nuclear. By 1990 we expect to have 25 000 MW of CANDU nuclear capacity in Ontario, supplying 65 to 70% of Ontario's electrical energy." Now all that deals with a program which I believe is scheduled as well as that for the production of the initial Pickering reactors and I expect it to go into action. This is not involving the change to thorium or the organic coolant. The change to thorium or the organic coolant I have said might be done by 1990 but the time is slipping by a bit and I think we'll soon have to put that a little bit further on, not because the technique is proving difficult but because everybody is so busy doing other things that they have no major program on the organic coolant. I think this is a real opportunity for the world, and it's interesting to trace it back in history. We have been consistent in this, right from 1952. We made one slight sidestep in going to a pressure vessel reactor from which we retreated at some cost in 1957, but since then it's all been on the basis of the pressure tube reactors with heavy water moderator [Lawand repeats question] yes, that of course is very low at Pickering: 29.2% is the net station efficiency quoted for Pickering. That's from the thermal energy to the net station electrical output. But when I mentioned the organic coolant I said that we were expecting an output of 38 or 39%. That is quite well documented and I think is as certain as the 29.2%.

DOSTROVSKY: I have two questions: one to Mr. Lewis and the other one maybe to our chairman. Dr. Lewis, this is a simple question. Perhaps some superior being tells you to go ahead and build the kind of reactors you have as fast as you can. How many reactors could you possibly build in 50 years? The other question refers to the last talk we had this afternoon. Certainly the presentation was very impressive, but the question is, What do we do next with this? Articles were written about this, references exist in the literature, analyzing somewhat these data. However, nothing much has been done. Maybe I should address myself to our chairman—could not one of the resolutions of this meeting (I understand we'll be discussing these in the next two days) be that someone or somebody would really undertake a serious analysis, underlining the suggestions by Prof. Dubos?

RANDERS: Thank you very much, Dr. Dostrovsky. It is a positive suggestion and I am sure many of us will think about it.

LEWIS: . . . to reply to this question. This is not an idle kind of question. The point is, whenever you're talking about 70 years on the people who will be doing that are not yet born let alone educated. So that one is really concerned with a whole national, international type of program that goes far beyond just building these reactors. I have said that no new scientific or technological breakthrough is needed. That, I think, is quite correct. We do not need to go beyond the technology that has been demonstrated. But even the next step of saying, build me one 1500 MW reactor with 39% net station efficiency is not something that you could hand to any engineer and expect him to go and do it with his own team. No. These things require a program, like the program that produced the Pickering reactor. Yes, it can be done. But, as I say, 1992 is more likely the date when that type would come in. Once that type came in, one would expect industry to be capable of taking it on. But there is a lot more than just industry who have got people, you've got questions of how in effect you're going to finance it, and who is going to take the responsibility for the operation and all the rest of it. This is a very, very big question. So that to answer, Oh, you can build just so many, doesn't really mean anything. You've got to start a long campaign of planning, educating people—giving a talk recently to the science teachers' association in Ontario, I said: You must know that Pickering has arrived from very successful cooperation. What we must expect from your students is both to be technically educated and to be educated in cooperation. That's very necessary. We could go even crazier than even some of the educational trends in which recently we had a little depression and very few engineers were seeking advanced education. That has changed where now all the graduate schools in engineering in Canada have turned that corner and they are filling up rapidly.

STEWART: I should like to change the subject from that addressed by my compatriot Dr. Lewis and address a remark to Professor Dubos. It appears to me, looking at it from the point of view of a physicist, that it is rather unfortunate that both fuel and food can be measured in calories. I believe that if we still had Professor Nordhaus here he, as an economist, would distrust this immensely. I must say that although I disagreed with a great many things he said, I would agree with him on this point. I do not believe that we can measure the value of an oyster or a lettuce in terms of its calories. It really appears to me that to define the efficiency of agriculture, as I have seen it done by many people—including Professor Dubos—in terms of calories output divided by calories input distorts the nature of agriculture. Neither the calories output nor, in particular, the caloric input is a true measure of the benefits or the costs of agriculture. The comparison is, I think, unfair. Certainly energy should be counted as part of the cost calculation in the efficiency of agriculture. Simply to take the output of agriculture and divide it by the number of people involved is not the correct calculation. But I think that the caloric comparison is unfair.

RANDERS: Does anybody else want to make a remark about this question?

JASKE: I'll just ask a simple question to Prof. Dubos. If he would summarize perhaps what he considers the three or four most important reasons why Western Civilization as we know it got into the situation of using more energy than they should? He has made a very educated and beautiful presentation of the fact that they are, but he didn't say anything about how we got there. I'd like to hear him use the same eloquence in that regard.

DUBOS: Well, you know the answer as well as I do. We got there because we have been so unfair in the way we have priced energy. As long as energy is dug out of the ground by someone else or is dug out of the ground by miners who are underpaid for the risk under which they work, you price energy at a level which is socially completely unfair. Because of that we become careless, rather careless—energy is so cheap . . . you know that better than I do. Energy has been made so cheap because we have exploited other people in all sorts of different ways. I think that if we had priced energy at the level where it should be, right from the beginning, we would have been much more careful in the way we used it. I did not equate a calorie of beef with a calorie of oil. What I spoke of is the cost of producing that calorie of beef or that calorie of any kind of food in terms of any other calories. The fact is that as the cost of energy increases, as it will and as it should, I think the cost of food will increase inevitably. We can't help it.

BLACKSHEAR: . . . In your speculation on the use of man's intervention in growing things, have you considered the use of enhanced crop residues as export energy?

KELLOGG: I'm afraid my question is not a very short one. I wanted to ask Dr. Dubos, since he is here, a question on a somewhat different subject. Many of us, considering the future a century or more ahead, are predicting a society where we have a sort of steady state; the population can't go on growing so it sort of levels off, and the per capita energy consumption can't go on growing so it levels off too. When I consider such a steady state society, I think about a remark that you yourself made in your talk on the occasion of getting the Institut de la Vie prize. You made the point that living organisms can only survive if they have to adapt to changes in their condition. The same thing is true of social structures, which must also continually evolve. This is a subject that has worried me, if we are indeed working towards a condition where society would be static. I find it hard to visualize this, and wonder if it isn't a very unfortunate condition to be working towards.

DUBOS: How can I answer without making silly statements? First of all, I still believe what I said then.

Speaking of planning, I'm always very much disturbed by the fact that the models that one creates—stable systems where no evolution occurs—one calls, as far as I can judge, planning as it is being discussed in the other room, is to a large extent trying to devise a system where our way will continue to be for another 1000 years. I think this is antibiological, that it cannot possibly function. So I do believe in the evolution of systems. On the other hand, I believe there are limits to the amounts of energy that one can use for all sorts of other reasons that are embedded in the physical system. But I think that our options, with regard to the production of energy, are very much more varied than what we have considered here. We have talked only about fossil fuels and we have talked about nuclear fuels. As some of you probably know, there are many people who have gone as far as demonstrating experimentally—which means that eventually it can be done in an actual operation—that one can even today on a small scale produce fuel, produce cellulose, by growing certain kinds of plants at a certain carbon dioxide concentration, at a price which is higher somewhat, but not very much higher than the fuels of today. I'm not speaking of solar energy because everybody has it in mind, but even with regard to renewable fuel systems or organic nature, as oil or coal is, it seems to me that we can even today develop a photosynthetic process which is so efficient in the use of solar energy, at about 5 or 10% carbon dioxide concentration, that there have already been designed and in operation, not plants, but some laboratory systems where cellulose is being produced as well. I cannot give you a reference. It's mentioned in a book. Is it called *The Conservation of the Earth*? Yes, which was published last year by a group of consultants on environmental and energy problems located in Washington. They have a chapter on it. Since I have tried to consult some of my colleagues in plant physiology who are better informed than I am on that, there is no doubt about it. There is no doubt that there are all sorts of plants which are not useful as food products but which are fantastically efficient with regard to fixation of solar energy. Water hyacinths, for example, which are a plague in the water course. If you think of growing it for the sake of growing cellulose, it comes to be a marvelous substance. I believe our societies will evolve completely; I believe our agriculture will evolve completely. But I think we will have to learn to do it within the constraints upon what I have called invariants of human nature and the invariants of the physical nature. But that leaves us plenty of room to navigate.

HUET: Je suis tout prêt à suivre la proposition du Prof. Dostrovsky que nous reprenions comme sujet d'étude certaines réflexions du Prof. Dubos dont le très grand mérite a été justement de nous faire réfléchir. Je voudrais faire tout de même deux observations à ce sujet. On peut concevoir qu'il y a un certain optimum de consommation d'énergie et la poursuite d'une croissance rapide et indéfinie dans ce domaine comme dans d'autres est un objectif absurde. Mais—et c'est là que je voudrais interroger le Prof. Dubos lui-même—si une croissance n'apporte pas toujours les satisfactions qu'on pourrait en espérer, une stagnation ou une décroissance est plus pénible encore et par conséquent il faut considérer qu'il y a une impossibilité à faire régresser les pays qui ont atteint un certain niveau et une tendance probablement irrésistible des autres pays à atteindre un niveau comparable. Par conséquent je crois qu'il faut tenit compte de ce phénomène. Et je pense qu'il faut tenir compte d'une autre donnée, dont le Professeur Dubos nous a peu parlé, sinon dans la réponse qu'il vient de faire à l'instant, mais dont nous avons traité davantage à notre première séance: ce qu'on a appelé les excès ou les abus de la consommation d'énergie, finalement était déterminé par des facteurs d'ordre économique et ce qui pourra se produire pour freiner l'accroissement de la demande d'énergie sera également déterminé par des facteurs économiques. Je rappelle qu'à notre première séance nous avons abordé la question des besoins futurs et de leur accroissement et on nous a dit—nous avons tous été d'accord sur ce point—qu'il y a dans l'évolution récente des facteurs de modération de l'accroissement de la demande d'énergie. La seconde question est alors celle-ci: si nous nous engageons dans une réflexion sur des problèmes d'éthique, dont je vois bien l'intérêt, est-ce que nous avons les moyens de traduire les conclusions auxquelles nous arriverons en consignes politiques effectivement applicables, sachant que finalement le régulateur de la consommation d'énergie c'est non pas un bilan théorique de la consommation et de la dépense des calories ou de toute autre donnée quantitative, mais un calcul économique des prix de revient. Le paysan ne se demande pas ce qui est entré d'énergie dans les tracteurs ou dans les insecticides qu'il utilise, il regarde ce qu'il peut produire ayant le meilleur prix de revient sur le marché et comment il peut augmenter sa production en utilisant des produits, qu'il cessera d'utiliser non pas parce qu'il se dira "Il y a trop d'énergie là-dedans", mais parce que ça lui coûtera plus cher et que ce ne sera plus rentable, tout cela étant gouverné par la loi de la rentabilité. Je veux bien que nous fassions une étude qui, encore une fois, me paraît intéressante et une réflexion qui me passionne sur un optimum de consommation d'énergie, mais ces deux facteurs que j'indique, dont le premier est social, en gros, et dont le second est économique, me paraissent introduire là-dedans des limitations et des régulations et je me demande comment notre réflexion pourra aboutir sur le plan politique, parce que c'est tout de même ce que nous devons chercher. Une fois de plus, je vais faire une réponse inévitablement superficielle en citant un exemple concret. Il se trouve que je suis engagé d'une façon pratique dans toutes sortes de problèmes aux quels vous avez fait allusion. On sait, tout le monde sait, ou devrait savoir, que la façon dont ce bâtiment—n'importe quel bâtiment—est construit est horriblement chère du point de vue de l'énergie qu'on y consomme. De plus, il n'est pas agréable; c'est important qu'il ne soit pas agréable, parce que ce fait me permet d'illustrer par un exemple ce sujet dans lequel je suis tellement engagé aux Etats-Unis: "Better Life through Less Energy",

une meilleure vie, améliorer la vie, en dépensant moins d'énergie. Alors prenez donc l'architecture—et il est important d'en parler parce que cette prescription s'est déjà exprimée aux Etats-Unis sous forme de nouveaux règlements quant à la construction. Or on sait que, du point de vue physiologique, nous utilisons beaucoup trop de lumière. Non seulement ça ne nous aide pas, mais ça a même des effets physiologiques désagréables. On sait d'autre part que la façon dont ces choses sont construites demande qu'on pompe de l'énergie pendant l'hiver pour réchauffer, qu'on pompe de l'énergie pendant l'été pour rafraîchir, alors qu'en changeant profondément l'architecture on peut économiser énormément d'énergie de ce point de vue-là. Eh bien je peux vous dire que nous avons des groupes d'architectes et d'ingénieurs, une école entière consacrée à ce sujet, dont le seul souci est d'essayer, d'apprendre à essayer de reformuler l'architecture de telle façon qu'elle soit beaucoup plus économique du point de vue de l'énergie et en même temps, pour revenir à notre sujet, cette architecture est beaucoup plus intéressante, la vie est beaucoup plus agréable. Quand j'essaie de synthétiser ce point de vue sous une forme un peu lapidaire, je dis; eh bien j'ai vécu à New York, à un moment où je n'avais plus d'argent, pendant l'été, où la température est si abominable, comme vous le savez, mais à ce moment-là je pouvais ouvrir mes fenêtres. Quand je suis devenu un peu plus riche—quand j'ai pu me le permettre—je me suis installé dans un bâtiment comme celui-ci, où on ne pouvait pas ouvrir les fenêtres. Et pendant tout l'été il fallait faire marcher la climatisation. Et maintenant que j'ai plus de liberté, je peux me permettre la fantaisie d'habiter dans un appartement où il y a une ventilation croisée et où je peux ouvrir toutes les fenêtres et où je n'ai plus jamais à me servir de climatisation à New York. Parce que je peux avoir une ventilation croisée. Et je peux vous assurer que c'est beaucoup plus agréable de vivre à New York avec des fenêtres ouvertes et ventilation croisée que ça ne l'est en essayant d'échapper à l'été en faisant tourner des climatiseurs. Et en fait, si j'ai une formule à défendre, et une formule qu'on peut défendre dans toutes sortes de domaines, c'est qu'il est possible d'améliorer la qualité de la vie, du point de vue de la santé physique, de la santé morale, la qualité du paysage, la qualité de l'architecture, l'utilisation des terres en utilisant moins d'énergie. Et cette formulation du problème a un sens économique, un sens social et peut-être convertir facilement, je crois en des actions politiques.

RANDERS: Thank you, Prof. Dubos. I think it's perhaps true, as Prof. Dostrovsky said, that some of your thoughts from your lecture and discussion ought to be reflected in the conclusions of this meeting. Maybe our rapporteur could manage to bring these up. Then I will thank everybody who has participated—both speakers and those who made interventions.

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FOREWORD

The aim of the INSTITUT DE LA VIE is:

— to start a permanent train of thought, both basic and applied, theoretical and practical, about life and the human condition, whether considering our species within the biosphere or mankind in all its dimensions;
— to bring together the highest authorities in science and technology in order to seek constantly, among the plurality of disciplines and of philosophies, the solutions that would best suit the needs and yearnings of human beings and so to assist in their decision-making those who are invested with the greatest responsibilities;
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The INSTITUT DE LA VIE organized, from 9th to 14th September 1974, a world conference on:

"TOWARDS A PLAN OF ACTIONS FOR MANKIND:
NEEDS AND RESOURCES, METHODS OF FORECASTING"

Participants to this conference were 236 belonging to 29 countries.

Five items were chosen, they were each subject to a preparatory colloquium in September and October 1973. The works of this colloquium were published in the book: "TOWARDS A PLAN OF ACTIONS FOR MANKIND, PROBLEMS AND PERSPECTIVES".[1]

The proceedings of the conference itself are published in five volumes.

This event will be followed by numerous others, prompted by the same will to carry on the human adventure and to enable man to live and to achieve himself.

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M. MAROIS

PRÉFACE

L'INSTITUT DE LA VIE a pour objet:

— d'engager d'une manière permanente une réflexion fondamentale et appliquée, théorique et pratique, sur la vie et la condition humaine, qu'il s'agisse de notre espèce dans la biosphère ou de l'homme dans toutes ses dimensions;
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L'INSTITUT DE LA VIE a organisé, du 9 au 14 septembre 1974, une conférence mondiale sur le thème:

"VERS UN PLAN D'ACTIONS POUR L'HUMANITE:
BESOINS ET RESSOURCES - METHODES DE PREVISION"

à laquelle ont participé 236 personnalités appartenant à 29 pays.

Cinq thèmes ont été choisis qui ont fait chacun l'objet, en septembre et octobre 1973, d'un colloque préparatoire. Les travaux de ces colloques ont été publiés dans l'ouvrage "VERS UN PLAN D'ACTIONS POUR L'HUMANITE - PROBLEMES ET PERSPECTIVES".[1]

Les actes de la conférence elle-même sont publiés en cinq volumes.

Cette manifestation sera suivie de nombreuses autres inspirées par la même volonté de poursuivre l'aventure humaine et de permettre à l'homme de vivre et de s'accomplir.

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Chapter I

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En ouvrant cette conférence, j'exprime à tous les participants, au nom de l'Institut de la Vie, nos souhaits chaleureux de bienvenue.

Je suis heureux de vous présenter les voeux pour la réussite de nos travaux de Monsieur Valéry Giscard D'Estaing, Président de la République française, qui a accordé son haut patronage à cette manifestation et de Monsieur Jacques Chirac, Premier Ministre.

Nous sommes devant le futur inconnu, une page blanche sur laquelle nous allons écrire une histoire neuve. Voici l'humanité confrontée avec elle-même, avec sa propre survie, son épanouissement et le problème des fins. Voici qu'elle est devenue un seul corps. Unité de destin. Voici qu'elle se heurte à la notion de limite.

Si la croissance exponentielle ne peut pas se poursuivre longtemps, le monde entrera à échéance prévisible dans des crises de survie. L'homme, être de besoin, subsiste en pillant la planète et rencontre sur le chemin de sa vie la multitude de ses semblables et la rareté des ressources. Besoin, multitude, rareté imposent une organisation technique et sociale rigoureuse, cependant qu'un combat de géants se livre entre les peuples pour la possession des biens. Et de nouvelles aliénations frappent la condition humaine. Aucune ne saurait faire taire les aspirations de l'homme. Et certain philosophe d'affirmer: pour leur permettre de s'exprimer, pour rejeter le poids de l'inerte, il n'est qu'une seule issue: le soulèvement, la révolte, la révolution, suivis de nouvelles retombées. Ainsi la marche de l'humanité apparaît-elle dans cette vision comme une passion sans fin que jalonnent des stations successives.

Est-il possible de substituer aux régulations paroxystiques par les crises, des régulations pacifiques, conscientes, grâce à une appréhension des données objectives du problème, en mobilisant les moyens de la science et le sentiment d'interdépendance, de solidarité, de communauté de destin?

La lutte pour la vie libère collectivement l'instinct de conservation et peut déchaîner toutes les violences. L'objet de cette conférence est de choisir le terrain des affrontements inéluctables. Faut-il engager la guerre des générations, la guerre de la vie actuelle contre la vie à venir, du présent contre le futur, réduire le nombre des naissances et, en nous comportant en "Gengis Khan de la banlieue solaire", léguer à nos descendants un monde inhospitalier, pollué, épuisé? Faut-il se résigner aux affrontements entre groupes humains? Ou devrons-nous chercher un armistice sur ces champs de bataille en affirmant la double solidarité: solidarité des générations, puisque, maillon d'un longue chaîne, nous sommes un moment de l'histoire de la vie qui doit se poursuivre dans la suite des temps, solidarité des hommes entre eux et interdépendance.

Cette interdépendance, cette solidarité reconnues, alors nous devons ouvrir un autre front, un front commun de l'humanité pour sa survie par l'aménagement du jardin de la terre, de la patrie terrestre.

Ayant ainsi choisi le terrain des combats, nous devons en définir les objectifs et les moyens.

Il est temps d'instituer une réflexion sereine sur le thème des limites de la croissance et sur les limites de ce thème.

Sur le fonds des mythologies politiques nourries de valeurs sociales telles la justice et la paix, les mythes économiques et techniques ont une intentionnalité plus précise, un rôle historique plus éphémère. La croissance est, selon Guillaume, un mythe majeur dont la fonction rationalisante, dans une situation historique donnée, est claire. Mais la notion de croissance n'a pas seulement un contenu économique et technique.

Nous devons faire éclater les catégories et tenter de déceler au-delà du tumulte des concepts parcellaires et des clameurs des désarrois une réalité plus fondamentale: la vie. La vie a une politique: persévérer, s'exprimer, conquérir, évoluer. L'un de ses drames est le divorce entre la surabondance des potentialités et la pénurie des moyens. "A quoi rêve une cellule: à devenir deux", écrit joliment François Jacob.

Une seule bactérie à qui l'on donnerait tous les moyens de se multiplier sans frein synthétiserait en huit jours une masse de matière vivante supérieure à la masse de la terre. Or il est bien vrai qu'une bactérie ne fabrique pas une terre tous les huit jours: il faut bien qu'elle accepte une sorte de régulation des naissances, qu'elle se heurte à ses propres limites. Ainsi, pour le biologiste, la limite n'est pas une idée neuve. La mort, n'est-elle pas pour les individus la limite suprême? Mais voici que la mort elle-même trouve sa place dans l'économie de la vie. Chacun des atomes et des molécules qui constituent notre organisme a été impliqué dans des milliards d'êtres vivants avant nous et notre dépouille servira à construire de nouvelles vies. Tel est le cycle du carbone, de l'oxygène, de l'azote, etc. Le recyclage non plus n'est pas une idée neuve. Ainsi la mort donne-t-elle de nouvelles chances pour de nouveaux essais, pour de nouvelles expressions du protoplasme, et le mouvement n'est pas brisé. Quelle leçon! Jamais la vie ne se résigne à la limite. Toute affirmation de la nécessité de la limite ébranle dans ses eaux profondes l'instinct de vie si elle s'érige comme un mur. Et le mur sera investi par l'élan de la vie, de nouvelles formes de dépassement seront trouvées.

C'est ici que la science intervient pour jouer un rôle déterminant. Elle peut faire l'inventaire des ressources de la planète, de leur mode d'utilisation, des possibilités de recyclage et relever ainsi le défi face aux nostalgiques passéistes qui la condamnent. La nécessité du recours à la science est proclamée avec vigueur par l'Institut de la Vie comme une réaction de santé. Evoquerons-nous Einstein: "Ce sera l'éternel honneur de la science d'avoir vaincu l'insécurité de l'homme devant lui-même et devant la nature."

Mais la science n'est qu'un moyen. Inévitablement se pose le problème des fins et la nécessité de leur formulation claire: développement de tout l'homme et de tous les hommes, style d'existence et qualité de la vie, modes de société, classement des priorités, tension dynamique entre compétition et communion, efficacité et poésie, biens matériels et béatitudes.

A ce point de la réflexion, l'heure sonne de l'appel à la haute politique. "Ce qui en philosophie est sens, en politique devient but." L'impuissance politique du pouvoir a pu être stigmatisée. Cette limite du pouvoir politique peut à son tour être dépassée. Le pouvoir trouve sa légitimité et sa puissance lorsqu'il ne méconnaît pas les lois de la vie et lorsqu'il sait exprimer les grandes aspirations humaines.

Nous sommes la vie dans la permanence de ses besoins, de son mouvement et de ses lois, la vie dans son changement et sa pérennité, nous sommes l'homme dans la fixité de ses structures et de ses constantes mais aussi dans la fluidité de ses adaptations aux situations qu'il se crée. Nous sommes le flot de l'histoire humaine, avec le tumulte de son passé et l'espoir indéracinable d'un avenir marqué de moins de zones d'ombre. L'Institut de la Vie crée-t-il une légende? Sans doute, au sens de la Légende des siècles, écrit-il la page contemporaine d'une geste qui revendique pour l'homme et pour son avenir l'honneur de vivre plus humainement la vie.

POURQUOI CETTE CONFÉRENCE?

J. COULOMB

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Le Président Marois m'a prié de retracer pour vous l'histoire prénatale de la présente conférence, d'une part pour montrer l'utilité de leurs efforts à tous ceux qui ont été associés à sa préparation, d'autre part pour faire sentir à tous les participants l'espoir qu'on met en eux. Plus modestement, quoique plus personnellement, je m'efforcerai de raconter comment un des membres du Comité d'organisation, géophysicien d'origine donc peu préparé à traiter les sujets qui vont vous occuper, s'est trouvé impliqué dans des tâtonnements successifs. dont nul ne saurait rougir ni même s'excuser puisqu'ils ont abouti finalement à une cristallisation correcte des buts poursuivis.

En 1967, Jacques Rueff, Chancelier de l'Institut de France, dont il est inutile de rappeler l'oeuvre en Economie Politique, publiait "Les Dieux et les Rois." Il tentait dans cet ouvrage de rassembler en une synthèse hardie les enseignements de la physique quantique et de la biologie moléculaire, ceux de la sociologie et de l'économie. Jacques Rueff s'efforçait de montrer la présence dans l'Univers de "niveaux d'ordre" successifs, le courant permanent qui les crée contrecarrant l'usure inévitable des structures. Dans cette vision unifiante, les individus qui appartiennent à un niveau d'ordre sont formés par "intégration" d'individus du niveau antérieur. L'économie politique étudie ainsi "l'effet des interactions fondées sur le désir des richesses, comme la physique, celui des interactions électriques ou magnétiques." A l'indéterminisme d'Heisenberg correspond le libre arbitre, l'intégration se fait en négligeant la diversité des êtres, et toute connaissance est d'ordre statistique.

Je me garderai d'aller plus loin, craignant de trahir la pensée de Jacques Rueff. Je dirai seulement que son livre fut discuté en 1968 lors de deux réunions auxquelles l'Académie des Sciences Morales et Politiques invita l'Académie des Sciences et que je fis imprudemment quelques remarques au cours de l'une d'elles. Cel adevait me valoir d'être invité il y a quatre ans par l'Institut de la Vie à faire partie d'un Comité français pour l'organisation d'une Conférence internationale sur les processus d'intégration en physique, en biologie et en sociologie.

La première réunion, à laquelle assistaient quelques-unes des personnalités ici présentes, se tint à Versailles le 21 novembre 1970. La complexité des phénomènes y apparut clairement mais aussi la nécessité de définir certains mots-clés: finalité (car on disputa fort sur le finalisme et les finalités), hiérarchie, information, objectivité, ordre, structure, système, val individu et société. Une clarification fut tentée le 16 janvier 1971 au cours d'une réun laquelle je ne pus me rendre.

Ces travaux préparatoires seront sans doute précieux le jour où convergeront vers leur cime les conclusions des réunions diverses organisées jusque-là par l'Institut de la Vie. N'appartenant pas à ses instances dirigeantes, je ne puis estimer la date à laquelle sera finalement discutée la Montée de l'Ordre dans l'Univers. L'important pour mon sujet d'aujourd'hui, c'est que de nombreux collègues signalèrent à cette occasion l'immense intérêt des méthodes d'analyse des systèmes pour la compréhension des phénomènes biologiques aussi bien que pour la modélisation des phénomènes affectant les sociétés humaines.

A cette époque d'ailleurs, le grand élan mondial vers la futurologie, amorcé vers 1957 par Gaston Berger et son Centre International de Prospective, avait pris l'ampleur que vous savez. Au MIT, le Professeur Forrester et le Professeur Meadows poursuivaient déjà les études que leur avait demandées le Club de Rome. On préparait la Conférence de Stockholm sur l'Environnement. L'idée venait donc, naturellement, et en conformité avec les buts premiers de l'Institut de la Vie, d'infléchir vers une application à la sauvegarde de l'humanité, les efforts qu'il voulait consacrer à la compréhension de l'Univers.

Ici encore, l'analyse des systèmes paraissait offrir l'outil indispensable. Le Professeur Marois prit donc son bâton de pèlerin, demanda à Monsieur Pierre Huet et à moi-même de l'accompagner, et nous partîmes pour l'Université d'York, à Toronto où le Professeur Medow organisait du 14 au 16 mai 1972 une réunion sur la modélisation, ayant particulièrement en vue les besoins des Nations Unies et les devoirs de la Communauté univeristaire internationale. Nous en revînmes fort instruits sur des complexités nouvelles, et conscients aussi du nombre de chercheurs et d'organismes variés qui empruntaient des voies parallèles pour guider le Monde vers un emploi plus raisonable de ses ressources. Il était évident qu'il fallait réfléchir encore avant d'entreprendre quoi que ce soit, et cela nous fut dit très explicitement par le Professeur Morgenstern qui avait assisté à la réunion d'York.

Le 14 septembre 1972, à l'occasion du Congrès International sur l'Homme et l'Informatique, un groupe restreint présidé par Monsieur Gibrat se réunit à Bordeaux pour remettre en chantier la présente conférence, qu'on pensait alors consacrer aux équilibres (ou aux déséquilibres) biologiques. Je n'étais pas à Bordeaux. Il semble que les personnalités présentes furent unanimes à souhaiter l'intervention de l'Institut de la Vie dans la bataille pour un monde nouveau, tout en soulignant l'importance d'une approche interdisciplinaire et dépourvue de tout dogmatisme. Monsieur Danzin, notamment, exprima son scepticisme sur la validité des modèles lorsqu'on s'approche de situations insoutenables; on voit alors apparaître, remarquait-il, des réactions d'adaptation de plus en plus rapides et de plus en plus imprévisibles.

J'espère que vous n'êtes pas lassés par mon histoire. En fait, nous approchons de sa fin. Le 7 octobre 1972, le Comité d'organisation, renforcé par la présence d'éminents économistes et d'un représentant qualifié des syndicats, se réunissait de nouveau. Entre temps, avait paru "The limits to growth", et l'opinion publique se passionnait pour l'avenir du Monde. Il était temps d'arrêter les décisions essentielles.

L'une d'elles, mes chers Collègues, ne nous coûtait guère mais vous engageait beaucoup. Elle consistait à ajouter au titre les mots "Plan d'Actions pour l'Humanité", c'est-à-dire à exprimer l'espoir que la Conférence, ne se bornerait pas à faire alterner sur chaque sujet les arguments pro et contra, mais qu'elle s'efforcerait d'amorcer un mouvement public dans une direction qui soit précise, tout au moins au point de départ. Bien entendu, il ne vous sera pas demandé de voter des résolutions, mais si un consensus se dégageait pour approuver le lancement d'actions immédiates, si l'Institut de la Vie faisait (comme il y est prêt je crois!) le nécessaire pour donner à ce consensus la publicité voulue ou mieux encore pour amorcer

des travaux collectifs, le bouillonnement produit contribuerait certainement à vaincre la redoutable inertie du monde où nous vivons.

Les autres décisions prises tendaient à faire précéder la Conférence internationale par une série de réunions restreintes sur des sujets spécialisés. Nous n'avions bien entendu aucun espoir de couvrir ainsi tous les problèmes, puis de les présenter à la Conférence et de la mettre en demeure d'adopter un point de vue sur chacun d'eux. Mais il est apparu au Comité d'organisation qu'on discuterait avec plus de fruit les questions générales si l'on avait considéré jusqu'au bout les difficultés présentées par quelques points particulièrement brûlants ou représentatifs.

La liste des réunions restreintes fut adoptée le 25 novembre 1972. L'une d'elles n'a pu avoir lieu. Elle portait sur un sujet qui paraissait passionnant, celui de la différenciation qui accompagne si souvent la croissance, sur cette espèce d'instabilité congénitale qui aggrave les disparités initiales entre individus ou entre sociétés. J'espère que Monsieur Philippe Huet nous en parlera tout à l'heure.

Les autres réunions restreintes se sont tenues en septembre et octobre 1973, avec les sujets suivants:

"Les formes d'organisation économique appropriées aux modalités de la croissance", réunion dirigée par Monsieur Malinvaud;
"Le recyclage des matières premières", organisée par Monsieur Guillemin;
"Les ressources énergétiques à long terme et la croissance", par Monsieur Gibrat;
"Les équilibres biologiques en face de la pollution thermique", par Monsieur Pérès;
Enfin, "La modélisation des systèmes appliquée à la prévision mondiale et ses limites", par Monsieur Davous.

Vous avez reconnu, avec une extension et sous des titres quelque peu différents, les sujets des cinq colloques plus larges qui se tiendront aujourd'hui et demain. Les résultats des réunions précédentes y seront bien entendu communiqués.

Concluez peut-être de ce long regard en arrière que les progès de la conscience universelle sont lents; l'essentiel est qu'ils ne soient pas impossibles. La route où vous avez bien voulu vous engager en venant jusqu'ici n'est pas une impasse, ni une voie complètement obstruée par nos prédécesseurs. Certes, l'Institut de la Vie n'est pas seul à jouer sa partie dans ce qui devrait être un concert de bonnes volontés. Mais je le crois conscient des solidarités nécessaires et résolu à ne pas durcir les antagonismes éventuels. Ainsi, devrait-il pouvoir compter sur notre concours raisonné.

PROGRÈS SCIENTIFIQUES ET VALEURS HUMAINES

P. Auger

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Oui, encore un plan d'action. Ce n'est pas, bien sûr, ni le premier ni le dernier du genre. D'ailleurs le titre de la présente conférence indique avec modestie: "Vers un plan d'Actions."

Il ne s'agit donc pas de bâtir une utopie mais de définir les voies par lesquelles nos sociétés humaines pourraient faire mieux en ce qui concerne l'exploitation et l'utilisation des ressources naturelles et humaines, c'est-à-dire tirer un meilleur parti de la nature qui nous entoure et, bien entendu de l'homme lui-même.

C'est d'ailleurs sur le côté proprement humain des organisations sociales qu'ont porté leur attention les auteurs d'utopies—depuis Thomas Morus—et beaucoup moins sur les problèmes posés par l'interaction de ces sociétés avec la Nature. C'est que ces derniers problèmes n'ont pris toute leur importance que depuis l'apparition de la Science expérimentale, puis de la révolution industrielle et de l'expansion démographique qui en ont résulté.

Les facteurs proprement humains n'ont, bien entendu, pas perdu leur importance et déjà au cours même de nos discussions préliminaires il avait été remarqué que ces facteurs peuvent influer de façon parfois imprévisible sur le cours des événements, dans certaines circonstances de crise.

Comme Jean Coulomb l'a indiqué dans sa présentation, c'est l'idée d'Organisation qui a constitué le germe initial des travaux de cette conférence, *effort d'organisation de l'avenir humain pour le progrès dans tous les domaines et par la volonté raisonnée de l'homme.* C'est en cela que je me suis permis de parler d'utopie, car l'espérance de jours meilleurs par la réalisation d'une utopie diffère profondément des espérances messianiques ou millénaristes qui se fondaient sur des interventions surnaturelles ou sur des fantaisies plus ou moins cycliques du destin. Les anciennes utopies étaient établies en tenant compte des conditions d'existence de l'homme à leur époque, et ne prévoyaient pas les grands changements à venir. Ceux-ci au contraire étaient escomptés par les anticipations comme celles de H. G. Wells, un peu oublié, mais dont le roman "Quand le Dormeur s'éveillera" m'est revenu en mémoire en visitant l'aéroport Charles de Gaulle avec ses passerelles aériennes à tapis roulant. Wells a aussi prévu les vidéocassettes et les automates. Et même les compagnies multinationales!

Mais revenons au plan d'actions et à l'évolution des organisations humaines dans leur interaction avec les phénomènes naturels. C'est ainsi que s'est réalisée au cours des millénaires l'évolution de l'humanité, cette évolution venant en quelque sorte prendre le relai de l'évolution des êtres organisés, des animaux en particulier. C'est ce qu'ont bien senti divers

penseurs, comme Jacques Rueff et aussi Julian Huxley, l'un du point de vue humain, l'autre en biolgie. J'ai moi-même développé ce point de vue dans "L'Homme microscopique".

Pourtant un examen plus approfondi de cette idée peut faire mieux comprendre le sens des efforts actuels. Dans la sélection darwinienne des organismes vivants, la seule sanction du succès est la survie de l'individu et de sa postérité. La sanction de l'insuccès est la mort de l'individu et l'extinction de son espèce. Ce type de sélection brutale s'est appliqué au cours de l'histoire à bien des conflits entre groupes humains, tribus, cités, nations. Mais dès que la transmission d'informations d'homme à homme a pris de l'importance, on ne peut plus comparer simplement la structure traditionnelle des groupes à l'ADN des cellules, car certains caractères sont transmis lors des conflits et des contacts passant d'un stock héréditaire dans un autre. C'est là une des raisons de la rapidité de l'évolution des sociétés humaines par rapport à celles des animaux.

Que serait-il arrivé si le Moyen Age avait consisté dans la destruction pure et simple, darwinienne, des civilisations gréco-romaines par les barbares?

Peut-être devrais-je signaler en passant que certaines bactéries semblent bien réussir à accélérer leur processus d'évolution par ce même dispositif, lorsque ces bactéries sont soumises à l'action d'un antibiotique. Lorsque l'une d'entre elles a muté (par l'action du hasard et de la nécessité) et a vaincu l'adversité, elle passe le secret à ses congénères moins heureuses, sous la forme de plasmides, de macromolécules porteuses d'information!

Mais tout de même, nous pouvons faire mieux que ces bactéries, et échapper à la sélection darwinienne parce que l'évolution des idées de l'homme n'est pas gouvernée par le hasard et la nécessité, parce que l'homme ne vit pas comme les animaux dans un simple présent, si programmé soit-il, et qu'il se projette constamment dans l'avenir. Il se pose des problèmes, ce qui n'existe nulle part dans la nature en dehors de lui. Il fait des projets. Il fait des plans d'actions. Mais il le fait, à titre individuel, par sa pensée, et celle-ci doit ensuite être transmise à d'autres hommes pour se répandre dans un groupe social. Car il n'y a pas de pensée collective, de conscience collective au sens rigoureux du terme. Et les idées qui ont le plus de facilité à se répandre dans les groupes sont les idées simples, historiquement ce sont des idées-forces telles que: puissance, indépendance, honneur et les idéologies en général. Entre les groupes humains, s'établit une sélection darwinienne, tempérée par l'échange des idées.

Peut-être pouvons-nous apercevoir une étape nouvelle après cette première évasion du Darwinisme, à l'instar des bactéries.

Il faut que l'homme ne se contente plus de progresser à tâtons, en quelque sorte, mais réalise sur le plan des rapports entre groupes sociaux ce qu'il a réalisé depuis trois siècles entre individus, sur le plan de la connaissance scientifique: je veux dire, qu'il prenne son destin en mains, consciemment, et en tant qu'espèce, l'espèce humaine, l'humanité.

C'est pour faire un pas de plus dans cette direction que l'Institut de la Vie vous a réunis.

QUEL CHAMP D'ACTIONS? UNE QUESTION POSÉE

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Le seul titre que je puisse invoquer pour m'adresser à votre assemblée est d'y avoir été instamment invité par l'organisateur de cette conférence, le Professeur Marois, Président de l'Institut de la Vie. Ceux d'entre vous qui le connaissent savent combien il est malaisé de se dérober à son invitation pressante.

A l'ouverture d'une session de travail comme la nôtre, il est utile de poser des questions, tout comme il est normal qu'à l'issue des travaux, les rapports de clôture n'y apportent aucune réponse définitive, mais qu'ils posent d'autres questions, plus précises et mieux adressées, traçant ainsi un véritable programme de recherche et de travail coordonné aux hommes de science un moment réunis.

Or, il est une question qui depuis longtemps me paraît importante au point que je souhaitais voir un groupe de travail particulier s'y attaquer en vue de cette conférence. Il s'agit des relations entre la croissance et l'inégalité du sort des hommes et des groupes, des collectivités, des nations auxquelles ces hommes s'intègrent pour y accomplir leurdest in terrestre.

Les évènements multiples survenus dans le monde au cours de la préparation de cette conférence n'ont fait d'ailleurs que confirmer l'actualité brûlante de ce thème de réflexion, tel cet évènement que l'on a baptisé tout récemment du nom de crise pétrolière, ou cet autre évènement mondial de prise de conscience commune que vient d'être la conférence des Nations Unies sur la population, réunie à Bucarest en août.

La question ainsi posée est hélas si ample, si mal définie, elle soulève aussi tant de passions qu'il m'est rapidement apparu impossible de l'attaquer, fût-ce dans quelques-uns seulement de ses aspects essentiels, avec les ressources indispensables de scientifiques des principales disciplines concernées, parvenus à entendre leurs langages divers en vue d'un travail commun. Et pourtant, souhaiterions-nous débattre d'un plan d'actions pour l'humanité en éludant ce problème, que les plus démunis, qui sont la majorité sur cette terre, viendraient nous en rappeler l'urgence avec de plus en plus de violence.

Certes il serait vain de s'interroger sur les sources de l'inégalité des hommes. Car l'inégalité fondamentalement est de la nature même: inégalité des constitutions biologiques, des santés, des dons physiques et mentaux, des aptitudes, des acquis familiaux, sociaux, des conditions climatiques, géographiques, des ressources du sol et du sous-sol; j'en passe. En revanche il serait intéressant d'étudier les origines de l'aspiration à l'égalité, puis de l'affirmation de celle-ci comme principe et fin de l'organisation sociale et de la condition humaine. Car il n'en fut pas toujours ainsi, tant s'en faut. Na...

furent, et de nos jours encore certaines sont fondées sur des principes autres, de différenciation fonctionnelle et de hiérarchie par exemple. Quant à la reconnaissance, par les grandes collectivités fondatrices ou héritières d'une civilisation, d'une dignité égale des autres peuples rencontrés sur la planète, il s'agit d'un acquis si récent et si abstrait encore qu'on peut douter de son enracinement profond dans les mentalités individuelles, et a fortiori collectives.

N'y a-t-il donc pas lien d'origine entre la philosophie occidentale du progrès par la science et la technologie, qui a accompagné et stimulé la croissance économique, et la reconnaissance d'un droit égal de tous les membres de l'espèce humaine à bénéficier de cette exploitation intensive des ressources terrestres, qui tend à fonder une nouvelle morale universelle? Quel est alors le contenu, de plus en plus exigeant qu'il convient de donner à cette noble aspiration? Egalité des droits, assez aisément reconnue mais aussi aisément dépourvue d'effet pratique, égalité des chances avec ses conséquences sur les systèmes d'éducation et de formation, mais aussi d'organisation du travail, égalité des situations, dont la revendication fonde aujourd'hui tous les systèmes se donnant pour but une "équitable répartition des fruits de la croissance", égalité des pouvoirs enfin, formelle puis réelle, principe de l'organisation démocratique et des systèmes de décision décentralisée, allant jusqu'à ce que l'on désigne, dans une grande confusion d'ailleurs, du terme ambigu d'autogestion. Mais, á moins d'admettre qu'il s'agit là d'idéaux inaccessibles, quelles limites faut-il assigner à la mise en oeuvre de ces principes pour en assurer l'application effective dans nos organisations économiques, sociales, politiques, et singulièrement dans l'organisation internationale?

Si nous passons alors de l'ordre des fins à celui des moyens, d'autres questions se posent, qui s'adressent plus précisément aux scientifiques de diverses disciplines, réunis pour conférer au sein de cette assemblée. L' essentiel est de savoir si la croissance économique, tenue longtemps, et aujourd'hui encore sans doute, comme l'instrument d'un progrès continu, et qui a fait naître l'espoir de l'abondance universelle, sinon du bonheur individuel, n'engendre pas des disparités accrues, inséparables du développement même. Peut-on définir et mesurer ces disparités, en analyser les mécanismes avec assez d'exactitude pour en contrôler et en corriger le jeu par des mesures appropriées? Quelle est l'efficacité réelle et la portée des politiques de maîtrise de la croissance, jusqu'ici mises en oeuvre afin d'humaniser celle-ci, quel en est le prix éventuel pour l'homme même, et quelles autres pourraient être imaginées?

Divers champs d'étude, complémentaires mais distincts, s'ouvrent ainsi à la recherche pluridisciplinaire.

1—Un premier thème pourrait reprendre les problèmes multiples de définition et de mesure, qui intéressent économistes et sociologues, et sur lesquels nous disposons déjà ici d'une contribution notable du professeur Benard, reprise dans le fascicule mis à la disposition de la conférence à la suite du colloque dirigé par Edmond Malinvaud. Mais nous sommes loin encore de posséder un outil satisfaisant et de parler un langage commun: comptes et indicateurs, hors le fameux P.N.B., restent incertains, controversés. Que faut-il entendre par disparités, et comment aligner les différences sans faire référence à un modèle unique, que l'on impose ainsi implicitement en idéal type à toute évolution? Bref comment comparer deux modèles sociaux différents? L'objectif, ou l'issue fatale, est-il celui d'une civilisation mondiale uniforme? En outre, même dans le cadre d'une collectivité apparemment bien intégrée, la dimension sociologique des différences de situation commence à peine à être explorée (intégration, hiérarchie, fonctions de représentation, d'intercession, degrés et niveaux de communication, etc. . . .). Comment faire progresser la prise en compte de ces

données, indispensables à la mesure des satisfactions ou frustrations profondes, éprouvées par chacun, et de quoi finalement est fait ce que chacun appelle son bonheur?

2—Un deuxième thème de recherche pourrait être centré sur les disparités sociales, dont les inégalités de revenus ne sont qu'un aspect comptable et partiel. Les études dans ce domaine sont plus avancées, soit que les mécanismes créateurs de déséquilibres aient fait l'objet d'hypothèses stimulantes, notamment en matière de qualifications humaines (intellectuelles ou professionnelles), en fonction des besoins de l'appareil de production en régime de croissance rapide, comme le fait magistralement ressortir le professeur Tinbergen, dont la contribution éclairante sur ce thème est un apport capital à nos travaux, soit que la coopération, encore timide mais prometteuse, entre économistes et sociologues sur la notion de consommation élargie, ou sur la définition d'indicateurs sociaux, ouvre la perspective d'une intégration d'éléments sociologiques (consommations de prestige, de représentation, conflit entre la recherche d'égalité et la conservation des hiérarchies de revenus comme facteur structurel d'inflation, par exemple) dans le domaine réservé des valeurs économiques.

Mais ces écarts de situation nés de déséquilibres partiels ou momentanés, et qui tendent à se consolider en rentes de rareté ou de monopole par toutes les pratiques restrictives de concurrence ou de cantonnement de marché (titres, diplômes, brevets, marques, par exemple), ne constituent-ils pas aussi l'un des moteurs de la croissance, l'un des stimulants les plus efficaces de la productivité? Comment dans une société évoluée corriger, ou atténuer ces écarts par les politiques de revenus ou de répartition, particulièrement par la fiscalité, sans énerver la croissance, sinon même en suscitant les réactions de défense et d'anticipation des mieux placés, alimenter une inflation génératrice de nouvelles inégalités?

En outre le problème posé, qui est apparemment de mesure et de degré dans l'écart tolérable, ne change-t-il pas de nature dès lors que l'observation plus attentive décèle une frange croissante de non-participants, d'inadaptés, d'exclus comme on les a nommés, que la société industrielle et urbaine semble secréter comme l'écume de sa croissance? Les mesures économiques de rattrapage, ou financières de compensation et de transfert, sont alors vaines, car c'est une réinsertion ou une insertion dans le corps social qu'il faut réussir par élimination des causes de rejet ou d'abandon. Plus le progrès et le changement qu'il entraine sont rapides, plus s'accroit le nombre de ceux qu'un handicap quelconque rend incapables de suivre le rythme et de s'adapter, et qui perdent pied. Si ces minorités, pour qui la croissance est amèrement négative, ne peuvent se faire entendre, elles deviennent rapidement sources de trouble et de violence, suscitant l'incompréhension et la réaction répressive d'une majorité portée, fût-ce à des rythmes inégaux, par le flux des dérivées du P.N.B.

3—Un troisième thème d'étude, fort instructif pour l'analyse du problème mondial du développement relatif, mais malheureusement encore peu exploité scientifiquement, est celui que fournissent les disparités régionales au sein des ensembles soumis à une autorité nationale ou fédérale commune. Comment ces disparités naissent-elles? Quel est le mécanisme de leur développement? Quelle est leur relation avec la croissance industrielle? Quel rôle y jouent la fonction "transport", ou sous un autre angle les institutions politiques et l'organisation territoriale?

Les politiques de décentralisation et d'aménagement du territoire jusqu'ici tentées pour corriger ces tendances ont-elles obtenu de réels succès? Les rares enquêtes sérieuses menées dans ce domaine à ce jour (au Canada par exemple) en vue d'évaluer les résultats de politiques correctrices conduisent à des conclusions décevantes, car elles semblent montrer que les efforts faits en vue d'aider au développement des régions déshéritées, bén[illegible] ment,

par des circuits de retour compliqués, surtout aux régions déjà prospères. Il est certain cependant que les solutions efficaces trouvées à ce problème de disparités régionales de croissance seraient fort instructives pour l'approche des difficultés, autrement sérieuses, posées par l'inégalité des développements nationaux dans le monde.

4—Car le quatrième thème, celui des disparités internationales de la croissance, et des écarts grandissants de prospérité et de richesse qu'elles créent, indiscutables en dépit des incertitudes de mesure déjà exposées, reste le thème fondamental des affrontements dans le monde contemporain. Les passions qu'il soulève, l'acuité qu'il atteint par moments font d'ailleurs que les débats sur l'avenir lointain de l'humanité, s'ils sont utiles et l'occasion parfois d'une prise de conscience éducatrice, restent cependant académiques et sans effet pratique appréciable, comme le démontrent à l'évidence les controverses et oppositions déclenchées ces dernières semaines à Bucarest. Quel est le sens d'une moyenne mondiale, peut-on même parler de problèmes de ressources ou de niveau d'existence communs à l'humanité dans l'état présent et prévisible des situations nationales et régionales sur notre planète, a fortiori, si l'on considère l'évolution constatée de ces situations? C'est d'un monde en divergence, sinon en voie d'éclatement, qu'il faudrait plutôt parler.

Ces risques et ces inquiétudes, qui nous touchent et nous concernent tous, avertis, négligents, ou inconscients, ne doivent pas dispenser les hommes de science que vous êtes de faire en ce domaine un effort redoublé d'analyse objective et de compréhension, avec l'espoir raisonnable qu'à l'occasion d'une crise plus grave, qui peut être prochaine, quelques-unes des idées lancées et des propositions constructives avancées après étude rationnelle, apparaîtront comme des solutions salvatrices. Il nous faut encore à ce propos remercier le professeur Tinbergen, qui, dans sa contribution au fascicule préparé par le colloque des économistes en vue de cette conférence, déblaie magistralement le champ de la recherche en présentant avec clarté l'essentiel de ce que l'on peut aujourd'hui énoncer objectivement sur ce sujet explosif. Y sont notamment exposés les obstacles de langage à surmonter si l'on veut s'entendre entre chercheurs de diverses écoles, mais d'égale bonne volonté, pour oeuvrer en commun.

En praticien de la coopération internationale, je pense, comme notre illustre collègue, que le travail d'analyse et de recherche de propositions constructives doit être centré sur la notion de rareté relative et différentielle des facteurs de production (l'homme, le capital, la ressource naturelle), rareté dont la disposition exclusive crée une rente, qu'elle soit appropriée privativement ou par des collectivités, nationales par exemple. Le changement de contrôle d'une ressource rare peut d'un coup réaliser d'énormes transferts internationaux, et modifier profondément les rapports de pouvoir dans le monde, comme l'exemple récent du pétrole l'illustre de façon frappante. De nouveaux problèmes d'adaptation sont alors créés, dont nous n'avons pas fini de découvrir l'enchaînement complexe. Il n'est pas évident que, faute de réflexion préalable et de préparation raisonnée, de tels évènements, au hasard des crises internationales, n'aboutissent à renforcer les positions relatives de puissance et de richesse plutôt qu'à corriger les écarts.

L'observation des évènements contemporains doit être poursuivie froidement, à la manière dont les historiens étudient le passé, et la lecture instructive doit en être faite à voix aussi haute que possible, si par bonheur un consensus d'hommes de science peut être dégagé sur l'analyse des faits. Est-ce trop demander aux plus doués des humains que de s'appliquer à surmonter leurs divergences naturelles dans l'intérêt de notre monde agité et divisé, et de mettre leur prestige au service des actions qui puissent assurer à l'humanité un progrès partagé, stable et pacifique?

Voilà quelques-unes des questions que fait surgir cet immense sujet des inégalités de la croissance, et qui relèvent à mon sens au premier chef et en une instance urgente de notre débat. Chacun, j'en suis convaincu, les avait déjà à l'esprit en abordant le thème plus précis de sa compétence. Mais dès lors que j'étais invité à parler, j'espère que l'on me pardonnera d'avoir ainsi exprimé, en termes imparfaits et sans aucun doute critiquables, les préoccupations que nous ressentons tous aujourd'hui. Je souhaite, en rappelant mon exorde, ainsi que l'a dit notre ami Jean Coulomb avec la foi communicative qu'on lui connaît, que notre conférence, par les conclusions auxquelles elle parviendra et par le programme d'actions, travaux et communications qu'elle recommandera, joue sa partie dans ce qui devrait être un concert de bonnes volontés à la hauteur de l'enjeu défini par l'Institut de la Vie.

L'ORGANISATION DES TRAVAUX

PIERRE HUET

Conseiller d'Etat, Membre du Conseil d'Administration de l'Institut de la Vie, Président de l'Association technique pour l'Energie nucléaire, 128 boulevard Malesherbes, 75017 Paris, France

Pour ne pas retarder nos travaux je me bornerai à appeler votre attention sur deux particularités de cette conférence. D'abord les cinq sujets qui ont fait l'objet des études préalables dont le résumé vous a été distribué et qui ont trait à la science économique, aux ressources minérales, aux ressources énergétiques, aux modifications thermiques et à la modélisation des systèmes mondiaux, sont des aspects particuliers choisis à dessein du complexe de problèmes que pose la croissance, au taux qu'elle a atteint aujour'hui dans notre monde moderne. Car il s'agit essentiellement de la prévoir et de la contrôler. C'est pourquoi il faut que ces sujets soient replacés et discutés dans ce même contexte.

Aussi, la conférence a-t-elle été prévue en deux phases: lundi et mardi, travail en cinq groupes sur chacun des cinq sujets pour permettre aux spécialistes de se concerter autant qu'on peut le faire en deux jours de débats sur la base des études préalables. Mercredi, jeudi et vendredi matin, des assemblées plénières doivent permettre une confrontation entre ces spécialistes et un effort de synthèse sur la base des travaux des groupes. Les travaux des groupes comportent des communications invitées dont vous trouvez la liste dans le programme et bien entendu des débats. Les travaux en assemblée plénière comportent un résumé des communications et, comme base de la discussion et de la confrontation d'ensemble, des rapports plus généraux qui s'appuieront sur les discussions des groupes afin d'en dégager les conclusions et ceci m'amène à mon second point.

Le titre de cette conférence "vers un plan d'actions pour l'humanité" peut paraître un peu ambitieux et même très ambitieux; il marque l'intention de ses organisateurs qu'elle ne se borne pas à des débats intéressants pour les spécialistes, mais qu'elle débouche sur des conclusions susceptibles d'inspirer ceux qui ont la charge de décider et d'agir. Si nous sommes fidèles à cette intention initiale, deux devoirs s'imposeront à nous: le premier est de tirer les conclusions de nos débats. En second lieu, puisque nous ne règlerons pas en cinq jours tous ces problèmes, il faut penser à ce que sera la suite de nos travaux de cette semaine. Car nous souhaitons—et je pense que les participants à ce congrès souhaiterons avec ses organisateurs —qu'ils ne soient pas un point d'aboutissement mais un point de départ.

Chapter II

ALLOCUTIONS AU DÎNER OFFICIEL

CONTENTS

ALLOCUTION PRONONCÉE

par M. Marois

Je remercie M. le Professeur E. Wolff, Administrateur du Collège de France, membre de l'Académie française, de l'Académie des Sciences et de l'Académie de Médecine, d'avoir bien voulu accepter de prsider ce dîner.

Sa présence ici revêt une signification particulière puisqu'embryologiste, il étudie la croissance dès les premiers jours de la vie.

"Qu'a donc rêvé l'homme depuis l'origine des temps, si ce n'est le Paradis terrestre, la Terre promise, le Jardin des Hespérides, l'Age d'or, l'Arabie heureuse, c'est-à-dire sous des noms divers l'empire de la nature et l'abondance." Ainsi s'exprime Guglielmo Ferrero. Face à ce rêve d'abondance se dresse la perspective de la limite. La poussée humaine de la vie sur une planète limitée, tel est le défi qu'affronte ce congrès.

L'homme mille fois fut assailli par la houle. Mille fois il la domina, puisque nous sommes ici, vivants, réunis en ce lieu. Nous voici de trente-six pays de l'Ouest, de l'Est et du Tiers-Monde. Voici que dix, vingt, trente disciplines échangent leurs informations, confrontent leurs méthodes, s'enquièrent des besoins, conjuguent leurs moyens, concertent leurs projets et vont définir un plan d'actions pour l'humanité, un plan d'actions non pour arrêter le mouvement de la vie mais pour lui donner toutes ses chances d'épanouissement et d'accomplissement.

Car la vie est mouvement, elle n'est pas lapathie routinière; la vie est conquête inventive, elle n'est pas l'insouciance ni l'abandon aveugle qui mèneraient au destin tragique. Par son dernier-né, l'homme, la vie est intelligence attentive, prise en main de sa propre histoire. Vous êtes cette intelligence attentive, vous êtes la science au service de la vie.

J'admire cet extraordinaire rassemblement d'intelligences armées des plus hautes connaissances. Vous résistez avec le même sang-froid aux entraînements collectifs des paniques. Vous êtes habités par le même sentiment d'appartenance au règne vivant, à la communauté humaine. Vous êtes animés du même désir de comprendre votre temps, du même souci de voir se développer et s'accomplir l'aventure humaine, de la même volonté d'organiser la planète et de léguer à nos descendants un monde propice à la vie.

Vous rejoignez par tous ces traits l'homme à qui d'abord l'Institut de la Vie doit d'avoir pu tenir ce congrès, le Président Ambroise Roux, Président de la Compagnie Générale d'Electricité. Il est l'un des plus hauts responsables de la vie industrielle française. Son sens de la responsabilité personnelle dépasse celui de ses propres entreprises pour atteindre à l'universel et son champ de vision embrasse les plus vastes horizons. Conscient des changements bouleversants de la condition humaine, il fut l'un des fondateurs de l'Institut de la Vie. Il sait avec audace ensemencer l'avenir, ainsi qu'en témoigne le plus récent exemple: ce congrès, auquel il a apporté une contribution morale et matérielle décisive. Souffrez,

Monsieur le Président, que je vous exprime, au nom de notre institution commune, nos sentiments de profonde gratitude.

Et c'est l'Institut de la Vie tout entier qui exprime maintenant sa fierté du haut patronage du Président de la République française, ses remerciements au ministère des Affaires étrangères, au ministère de l'Education, au ministère de la Qualité de la Vie, son ardente reconnaissance aux comités internationaux et français d'organisation et à tous les participants de cette conférence.

Celle-ci, nous l'espérons, se réunira tous les quatre ans et le courant de pensée qu'elle crée confluera un jour avec celui des grandes conférences de l'Institut de la Vie "De la Physique Théorique à la Biologie". Nous espérons alors atteindre à une vision globale des processus d'intégration en physique, en biologie et dans les sociétés humaines, vision inspirée, proposée par le Chancelier Jacques Rueff, aux ambitions suprêmes de notre institution.

Car l'Institut de la Vie nourrit d'ardentes ambitions. Il ne s'occupe pas seulement de la vie mais des vivants. Il suscite des fondations, engage des actions permanentes pour prévenir les handicaps physiques et mentaux, pour lutter contre le fléau parasitaire si redoutable dans les pays en voie de développement, pour améliorer les conditions de vie dans les villes, pour mesurer le retentissement sur la vie de l'homme et des sociétés, des progrès scientifiques et techniques tels l'ordinateur, bref pour diminuer le poids de la souffrance humaine ou réduire les contraintes et pour répondre à l'appel de leurs rêves irrépressibles.

Ces rêves, il les illustre et leur donne un visage par les prix qu'il a créés: 5 prix de 250 000 Frs à 300 000 Frs chacun, distinguant des hommes qui ont bien mérité de la vie soit pour l'avoir défendue soit pour l'avoir illustrée. Cinq thèmes ont été choisis: la valeur de la vie, l'environnement, l'environnement urbain, l'éducation, l'espérance humaine.

Nous refusons le pessimisme radical invitant à brûler l'instant au brasier de l'ultime fête et notre espérance n'est pas utopie.

Un monde meurt, un autre naît. Même si nous sommes attentifs aux signes du déclin, nous le sommes plus encore à ceux de la naissance et du renouveau. Nous sommes plus sensibles aux palpitations de l'aube qu'aux derniers feux du crépuscule.

Certes, le défi est immense que lance le siècle. Et le vertige peut saisir les plus lucides.

Mais, au sein de l'Institut de la Vie, il renforce ceux qui ont pris la mesure de l'homme pour avoir pris la mesure de l'histoire de la vie, histoire forgée par 30 millions de siècles et que 60 millions de siècles appellent. Eduqués par cette fabuleuse histoire, ils savent la volonté d'être, l'opiniâtreté, les ressources de la vie et ils misent sur la force de l'esprit pour conjurer ce que la faiblesse et le sentiment de la mort appellent la fatalité ou le destin tragique.

Une volonté de comprendre, de prévoir et d'agir, sous-tendue par l'admiration et l'amour de la vie, anime l'Institut de la Vie pour les plus grands accomplissements de l'homme.

ALLOCUTION PRONONCÉE

par Etienne Wolff

de l'Académie française et de l'Académie des Sciences

Le président de l'Institut de la Vie, mon ami Maurice Marois, m'a demandé de vous dire quelques mots sur la croissance.

En ma qualité de biologiste et d'embryologiste, je ne peux évoquer que des phénomènes de croissance chez les animaux. Mais, comme toute science humaine cherche des modèles dans les sciences de la nature, peut-être la comparaison avec l'ontogenèse des animaux a-t-elle un certain intérêt pour vous. C'est à ce sujet que j'aimerais vous livrer quelques réflexions, non pas dans un rapport documenté—vous en avez beaucoup entendus, mais à bâtons rompus, comme il sied à la fin d'un repas d'une fin de congrès.

Ce qui caractérise la croissance de la plupart des organismes vivants, c'est qu'elle tend vers une limite. Elle commence dès les jeunes stades du développement embryonnaire, elle se poursuit après la naissance jusqu'à la maturité, puis elle s'arrête. Il en est ainsi de la croissance générale du corps, non de la croissance de certains organes et tissus: l'hypertrophie de la prostate, l'épaississement des os, l'obésité, c'est-à-dire la prolifération de tissu adipeux, la poussée des cheveux, des ongles, nous en donnent de bons exemples. Mais en moyenne la croissance s'arrête à la maturité. C'est le stade où l'anabolisme et le catabolisme s'équilibrent, comme disent les physiologistes, c'est-à-dire où l'assimilation compense à peu près la désassimilation.

Pourquoi la croissance s'arrête-t-elle? Tel est le grand problème. Pourquoi s'arrête-t-elle même dans un organisme bien nourri, soumis à des conditions optimum de milieu? Bien que le problème ne soit pas encore résolu, certains renseignements précieux nous sont donnés par la culture des tissus in vitro.

L'arrêt de la croissance n'est pas dû aux cellules qui composent un organisme. Si l'on met en culture des cellules d'un organe quelconque, elles peuvent se multiplier indéfiniment, sans limite d'espace et de durée. Vous savez à quels calculs un peu puérils on se livre parfois dans certaines publications: si l'on donnait à certaines cellules telles que les fibroblastes toutes les possibilités de prolifération, en quelques mois, elles envahiraient le monde! Si au contraire nous cultivons des organes embryonnaires, tels un tibia, un estomac, un pancréas, comme nous l'avons fait dans mon laboratoire, on n'arrive jamais à le faire croître plus de quelques jours, au plus une ou deux semaines. Dans un ensemble organisé, des interactions inhibitrices se manifestent, qui règlent et coordonnent la croissance des différents tissus. Ainsi se constituent des organes bien proportionnés, dont la croissance est limitée dans le temps et dans l'espace. Il existe donc entre les tissus d'un organe des facteurs régulateurs, inhibiteurs et coordinateurs.

Une chose très remarquable est que cette inhibition n'existe pas pour certains organes ou tissus cancéreux, que nous avons pu cultiver pendant de longues années, sans qu'ils

perdent ni leur pouvoir de prolifération ni un certain degré d'organisation. Ainsi nous cultivons et multiplions des cancers du tube digestif depuis respectivement 1, 2, 10 et 13 ans, alors que les sujets dont ils proviennent sont morts depuis ces mêmes durées. Nous voyons donc se révéler en culture in vitro les mêmes caractères que le cancer manifeste in vivo: l'absence de contrôle d'un tissu par un autre ou par les autres parties de l'organisme.

Y a-t-il, malgré la règle générale, des organismes à croissance illimitée? Il y a ceux qui n'ont pas une forme spécifique bien définie, ceux qui possèdent la faculté de bourgeonner: plantes à stolons et à propagules, animaux bourgeonnants, comme les éponges, les hydraires, les coralliaires, les bryozoaires. Ce sont des organismes qui n'ont pas de limites rigoureuses, qui en quelque sorte débordent vers l'extérieur.

On considère aussi comme des organismes à croissance indéfinie, mais non illimitée, certains poissons plats comme la Sole, la Plie, qui continuent à croître toute leur vie, avec cependant un ralentissement vers la 12ème année. Mais on n'a encore jamais vu de plie de la taille d'une baleine, ce qui prouve qu'elle subit quand même certaines inhibitions, ou qu'elle ne vit pas assez longtemps pour atteindre de telles dimensions.

En général, une espèce a une forme et une taille spécifiques. C'est dire qu'elle ne peut dépasser certaines dimensions. Mais celles-ci varient entre des limites, qu'on peut plus ou moins modifier. Chacun sait que la taille moyenne des Japonais a beaucoup augmenté au cours des dernières décennies, de même que la taille des conscrits français depuis le début du siècle. Ceci est vrai de la population de presque tous les pays "développés". Plusieurs facteurs interviennent dans les potentialités de croissance d'une espèce.

— Il y a d'abord le patrimoine génétique, qui est une constante stable, sauf dans l'éventualité de mutations. Il impose a priori certaines limites à la croissance.
— Il y a en outre les facteurs externes, qui permettent, à l'intérieur des limites spécifiques, de réaliser le potentiel optimum.

Parmi eux, le facteur primordial est l'alimentation. Un autre, non moins important, est l'intervention d'hormones, telles l'hypophyse, qui joue un rôle considérable. On connaît par exemple une race de souris naines, dont le poids habituel ne dépasse pas 5 g. Ces souris possèdent un gène dont l'effet est d'empêcher la synthèse de l'hormone de croissance par l'hypophyse. Il suffit de leur administrer chaque jour une certaine quantité d'hormone de croissance pour qu'en quelques mois leur poids augmente dans la proportion de 1 à 10, donc atteigne 50 g.

Sans vouloir entrer dans des considérations mathématiques, qui ne seraient pas de mise ici, je voudrais signaler que le rythme de croissance de l'organisme total n'est pas le même que celui de ses parties. Mais il existe entre la croissance totale et la croissance de chacun des organes un rapport constant qui s'exprime par une courbe exponentielle. C'est la loi de l'allométrie qui a été démontrée par Huxley, d'Arcy Thompson en Grande-Bretagne, en France par Georges Teissier. Elle exprime que la croissance de chaque organe n'est pas quelconque et aléatoire, par rapport à celle de l'organisme entier. Elle suit une loi bien définie. Un changement de pente de la courbe (droite d'allométrie) permet de soupçonner qu'un nouveau phénomène métabolique est intervenu: ainsi ont été découvertes ou pressenties certaines hormones, par exemple la glande androgène des Crustacés par Madame Charniaux-Cotton.

Un exemple très caractéristique de la loi d'allométrie est l'évolution du rapport entre la longueur de la tête et celle du corps de l'être humain. Toutes proportions gardées, le bébé a une très grosse tête par rapport au corps; chez l'adulte, elle est relativement beaucoup

plus petite. C'est que la tête est la partie de l'organisme qui se développe le plus tôt chez l'embryon. Elle est très en avance sur le corps. Celui-ci ne rattrape son retard qu'à l'âge adulte. Ainsi la longueur de la tête est la moitié de celle du corps, chez l'embryon de 2 mois, le rapport est encore de $\frac{1}{4}$ à la naissance, il est de $\frac{1}{8}$ à l'âge de 20 ans. Entre la tête et le corps existe une loi d'allométrie qui permet d'exprimer et de prévoir leurs dimensions respectives pendant toute la croissance.

Je voudrais, pour terminer, évoquer un autre aspect de la croissance: c'est la croissance des espèces au cours des âges, le développement paléontologique. Certains animaux ont parcouru une évolution dont on peut dire, à titre rétrospectif, qu'elle était orientée. Il y a une continuité de variation de plusieurs organes, et aussi de la taille de l'animal: ainsi dans la lignée du cheval, il y a une variation continue, dans un sens déterminé, des pattes, des dents, des dimensions du corps et de bien d'autres caractères. L'ancêtre du cheval, Hyracotherium ou Eohippus, avait la taille d'un renard. On peut parler d'orthogenèse, en ce sens qu'on a l'impression, qui n'est pas une illusion, que tous les caractères ont convergé vers le type du cheval actuel. On peut dire de lui, bien que ce soit un anthropomorphisme, qu'il a réalisé la perfection du type caballin.

Il est beaucoup de lignées qui sont atteintes de gigantisme: les grands Reptiles du Secondaire, beaucoup de Mammifères du Tertiaire, qui ont atteint des dimensions énormes. Il ne reste plus beaucoup de ces animaux ultra-géants. La plupart des espèces se sont éteintes. Et la question se pose: pourquoi? On peut invoquer la raréfaction de la nourriture pour des animaux dont les besoins sont énormes, ou, ce qui revient au même, la concurrence pour l'aliment entre individus devenus trop nombreux, mais aussi l'apparition de conditions défavorables de milieu pour des bêtes très sensibles à toute variation de climat, ou, qui sait, quelque pollution préhistorique!

L'influence de l'homme est actuellement très défavorable à certaines espèces, dont il provoque ou accélère la disparition. Prenons l'exemple des Cétacés, au nombre desquels on trouve les plus grands Mammifères actuels. Certains ont des dents, tels les Dauphins, les Cachalots; ils se nourrissent de grandes proies, en particulier de grands Poissons, qui peuvent venir à se raréfier ou à manquer. D'autres, tels les Baleines, ont des fanons qui filtrent l'eau de mer; elles se nourrissent de très petits animaux ou végétaux qui constituent le plancton; cette micro-faune pullule dans toutes les mers et sous toutes les latitudes. Il est inconcevable que le plancton, à moins d'une disparition de toute vie sur le globe, puisse venir à manquer. La baleine est un des animaux les mieux adaptés, malgré son gigantisme, à trouver sa nourriture. C'est probablement à cause de cette adaptation qu'elle a pu atteindre des dimensions si énormes. Il y a aussi la sécurité qu'elle trouve dans les mers où elle n'a pour ainsi dire pas d'ennemis parmi les grands animaux. On peut donc être assuré que, si elle vient à s'éteindre, ce ne sera pas faute d'aliment, mais à cause de la chasse effrénée que lui donne l'homme. Le gigantisme n'est pas en lui-même une cause de disparition. La croissance démesurée de ces espèces n'est donc pas nécessairement défavorable à leur survie. Les causes de la disparition des espèces géantes sont multiples. On ne peut s'empêcher de penser que, si les baleines avaient la taille de poissons ordinaires ou de petits Mammifères, elles n'offriraient pas à l'homme de cibles aussi faciles. On voit la complexité des phénomènes. Les grandes espèces marines ont d'abord trouvé dans les Océans un milieu favorable à leur croissance et à leur survie. Avec l'apparition de l'Homme, elles n'ont plus aucune sécurité. C'est sur la complexité des phénomènes de croissance évolutive, sur l'interaction des facteurs héréditaires et des facteurs externes, sur les réactions en chaînes qui se produisent dans le monde vivant sous l'influence du milieu que je voulais attirer votre attention.

Chapter III

:CONOMIC SCIENCES AND PROBLEMS OF GROWTH

Président: M. ABRAMOVITZ

CONTENTS

INTRODUCTION

M. Abramovitz

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I call this first plenary meeting of the Congress to order. My name is Moses Abramovitz and I am to be your chairman for this morning. As you know, this is the meeting at which the group of economists in the Congress are going to present such views as they have been able to put together about our problems. We economists often have our attention fixed on much more commonplace questions than this Congress raises, but during the last few days we have been doing our best to consider the problems raised by economic growth, looking as best as we can at the very long-term future. We have considered the problems raised by possible shortages of materials or energy or environmental pollution. We have tried to consider these matters in terms of the difficulties or problems that would be raised for poor as well as rich countries; for the poor in the rich countries as well as those in poor countries. We have tried to consider problems raised by a slowdown in the growth of population or in output per capita as well as questions raised by continued rapid economic growth.

Needless to say, we found that we had certain differences of opinion. At the same time we also found a very considerable measure of agreement in the way in which we approached these questions. And in these circumstances we have asked Prof. Edmond Malinvaud, who is on my left, to make a general statement concerning the problems of long-term economic growth and the possible ways of dealing with them as we see them. He is now going to try to express the consensus of our opinion. It is then my plan, after the completion of his general statement, to invite questions or statements from any member of the Congress. Either Prof. Malinvaud will reply, or, if it seems more convenient, some other member of the panel of economists who are seated here or perhaps in the audience, will reply.

RAPPORT

E. MALINVAUD

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Abstract. Forecasts as to long-term economic growth must be considered before the preparation of programmes is discussed.

I

The recent debates as to the future of economic growth all too often neglect the scientific work that has been done by economists for explaining past growth; even though it is not very conclusive, this work has direct significance for the debates. The idea of limits to growth is not new. Fears expressed in the past all turned out so far to be unjustified because substitutions and technical progress occurred. Economists are very dependent on other scientists for information concerning the physical limits to growth. Unfortunately the available information reveals wide uncertainties as to the existence of global limits that would matter before long. We realize that the equilibrium between population growth and the progress of food production remains the crucial issue. The risk exists that the rapid growth of the past two centuries will soon now reach a turning point because of increased scarcities. Should difficulties appear because of the occurrence of this risk, they will mainly concern some particular regions of the world.

II

When economists approach the study of programmes, they proceed to two types of analysis, the first one considering only physical constraints, the second one taking also sociological and institutional constraints into account. Models are often used, but they must correctly represent the constraints and aim at objectives correctly representing social choices. For planning future growth difficult equity considerations must be faced: between the main regions of the world, between present and future generations. Since uncertainties are huge, most economists tend to favor a cautious policy that would pay particular attention to scarce resources and environment. But such a policy does not require that the growth of aggregate production be stopped. Two types of instruments may be used for the control of economic growth—direct quantitative controls and actions on the price system. Modern economists are not dogmatic in the choice between the two; they know however, that non-economists are often mistaken in relying too confidently on quantitative controls and in their distrust of actions through prices.

Since scarcities are alarming, mainly for some regions of the Third World, the best policy may be to promote economic development in these regions; this will not be easy if economic growth is greatly slowed down in the richest countries.

C'est un honneur pour moi que d'être le premier à vous rendre compte en séance plénière des travaux de nos groupes spécialisés. Mais c'est aussi une tâche difficile, car il est délicat pour tout savant de présenter à une vaste audience ce que sa discipline peut apporter pour la solution de problèmes complexes qui ne relèvent pas uniquement de cette discipline. Plus que mon exposé, la discussion qui suivra devrait permettre une meilleure compréhension mutuelle entre les économistes et leurs collègues d'autres sciences.

Je ne cacherai pas en commençant l'existence de divergences d'opinions entre les économistes. J'espère que les exposés de mes collègues et la discussion feront apparaître l'origine de ces divergences: elles ne concerneront pas les méthodes d'analyse, mais les préférences

ou jugements de valeur que chacun de nous formule quant aux diverses stratégies grâce auxquelles nous pouvons faire face aux problèmes qui nous confrontent. Mon exposé de synthèse vise à présenter l'ensemble des conclusions sur lesquelles un accord existe entre nous, quoique des divergences subsistent quant à l'accent à attribuer à telle ou telle considération.

Tous les économistes présents ici sont d'accord sur l'utilité de la présente réunion. D'une part les problèmes desquels nous avons à débattre sont d'une telle importance pour l'avenir de l'humanité qu'ils interdisent aux savants de rester en repos; d'autre part, trop peu d'occasions telles que celle-ci nous sont offertes pour confronter ce que les spécialistes des différentes sciences ont à dire vis-à-vis de problèmes qui les concernent toutes simultanément.

Pour vous présenter notre message, je vais adopter un plan en deux parties. Je parlerai d'abord du diagnostic que nous portons sur la situation présente et des prévisions que nous pouvons formuler quant à la croissance économique. J'exposerai ensuite brièvement comment nous concevons la préparation de programmes d'action.

1. OU VA LA CROISSANCE ECONOMIQUE?

1. Nous devons d'abord faire remarquer que les débats actuels négligent souvent de se pencher sur l'évolution passée, comme s'il n'y avait rien à apprendre de l'étude objective de l'histoire économique. Quelle aberration que de croire pouvoir bien planifier l'avenir sans avoir préalablement fait tous les efforts possibles pour comprendre le passé!

Dans les textes que nous avons soumis(1), nous avons tenté de montrer que des économistes consacrent toutes leurs recherches à la compréhension de la croissance que le monde a connue jusqu'à ce jour. Nous voudrions vous convaincre que cet effort n'est pas totalement vain.

Toutefois, je dois dire immédiatement, et c'est un thème qui reviendra souvent par la suite, que notre compréhension reste très incomplète; nous sommes très incertains pour prévoir certains facteurs fondamentaux qui détermineront le rythme de la croissance future. Dès l'abord, la prévision à long terme s'avère comme extrêmement aléatoire.

2. L'idée de limites à la croissance n'est pas nouvelle. Elle a été avancée de façon répétée à de nombreuses reprises depuis le début du XIX^ème siècle. De façon répétée, les prévisions pessimistes qui furent alors proférées se sont révélées inexactes. Ce n'est évidemment pas une preuve que les prévisions pessimistes actuellement formulées n'aient pas à être prises en compte; j'y reviendrai. Mais ceci peut donner matière à réflexion.

Parmi les raisons expliquant les erreurs passées figure une tendance à sous-estimer les facultés d'adaptation de nos activités économiques. Ces adaptations se réalisent par ce que nous, économistes, appelons d'une manière générale les substitutions et qui couvrent la transformation des modes de consommation, le remplacement d'une matière première par une autre, la découverte de nouveaux modes de fabrication qui permettent de se passer de certains facteurs de production devenus rares, etc.

Si nous voulons prévoir au mieux la croissance future nous n'avons aucune raison de supposer que ces possibilités de substitution vont disparaître du jour au lendemain. Si nous voulons organiser au mieux cette croissance, nous devons veiller à favoriser ces substitutions partout où elles apparaissent souhaitables.

3. Nous interrogeant plus directement sur les limitations qui feront obstacles au développement du monde, nous, économistes, sommes très dépendants de ce que nous pouvons

apprendre des autres savants; nous n'avons aucune compétence qui nous permette de juger du bien-fondé de prévisions faites par les experts en énergie, matières minérales, etc.

En fait, nous souhaiterions recevoir des informations qui, obtenant l'accord de tous les spécialistes de chaque branche, fassent apparaître les disponibilités physiques en ressources des diverses catégories, l'impact des progrès techniques futurs, l'évolution de la population, etc. Nous recherchons ces informations et sommes parfois dans la perplexité, tantôt en face de la diversité des opinions exprimées, tantôt à cause de la difficulté à traduire certains faits ponctuels en un phénomène d'importance globale. Nous espérons que cette conférence va nous permettre d'y voir plus clair.

Prenant en compte les informations à notre disposition, nous avons le sentiment de nous être mal exprimés dans la déclaration de synthèse figurant au début de l'ouvrage préparé pour ce congrès.[1] A la relecture, cette déclaration, qui reconnaît clairement les incertitudes de la situation, nous fait craindre cependant que vous nous considériez comme ayant, vis-à-vis des obstacles possibles à la croissance, une attitude au total optimiste.

Que cette impression puisse se dégager provient peut-être de ce que nous avons réagi trop vivement à des affirmations péremptoires qui, présentant les obstacles comme certains, exagéraient leur importance. Mais ceci résulte aussi de deux lacunes sur lesquelles je dois m'expliquer.

4. En premier lieu nous nous sommes exprimés à partir des informations qui étaient à notre disposition l'an dernier et en pensant surtout aux réserves en énergie et en matières premières minérales au sens strict; ces informations ne semblaient pas justifier un pessimisme systématique. Depuis, certains d'entre nous ont révisé leur jugement. Ils pensent à des prévisions faites récemment quant au déséquilibre entre la croissance de la population et celle de la production alimentaire; ils sont inquiets à prendre connaissance des difficultés sur lesquelles certains biologistes et écologistes attirent l'attention et qui compromettraient la possibilité de progrès rapides de la production agricole.

On peut d'ailleurs regretter, soit dit en passant, que, dans cette conférence, les questions de population et d'alimentation ne soient pas abordées de façon beaucoup plus systématique; car elles risquent d'être au centre des débats.

De plus nous avons poursuivi notre réflexion et il nous est apparu que, pour certains des obstacles envisagés, les adaptations de notre croissance économique seraient difficiles à réaliser. Nous concevons assez facilement comment les substitutions entre matières premières s'opéreront de manière plus ou moins spontanée et plus ou moins régulière. Mais nous avons pris conscience de ce que ni les comportements décisionnels, ni les institutions actuelles ne nous donnaient beaucoup de garantie pour freiner le développement de certains effets nuisibles qui ne se concrétisent pas par la disparition immédiate de biens appropriables, tels que les ressources minérales, mais qui jouent à long terme et parfois uniquement à l'échelle de la planète.

5. Ainsi, s'agissant de l'utilisation des ressources de la planète, nous ne voudrions pas affirmer que les prochaines décennies se situeront dans la continuité du siècle passé au cours duquel les raretés eurent tendance à se réduire ou tout au moins à ne pas s'accuser: ni les ressources minérales ni la terre n'ont manqué depuis 100 ans.

Il est possible, il est même probable, qu'un tournant a été pris et que les raretés vont croître. Le feront-elles d'une manière qui, envisagée sur la longue période, exercera des effets lents et tout à fait compatibles avec la poursuite d'une bonne croissance? Joueront-elles au contraire de manière accélérée en imposant un freinage énergique de cette croissance? Il nous faut reconnaître ensemble ici que personne ne peut trancher ces questions, mais

que nous devons les garder présentes à l'esprit dans nos recherches et que nous devons concevoir nos recommandations comme concernant un monde sujet à d'énormes incertitudes.

6. La seconde lacune de notre texte tient à ce que, suivant en cela bien d'autres travaux, nous y considérons le monde comme un tout. En fait, avec les divisions politiques actuelles, la répartition très inégale des ressources et des hommes entre les pays, l'étendue très limitée de la coopération internationale, une catastrophe planétaire de l'humanité se heurtant à des barrières physiques est une image peu réaliste. Si elles doivent se produire, les difficultés se localiseront, et dans des régions du monde que nous pouvons d'ores et déjà identifier, tout au moins pour la plupart des obstacles auxquels on pense aujourd'hui.

Cette dimension régionale a de l'importance pour deux raisons: elle peut beaucoup affecter les répercussions politico-sociales des difficultés éventuelles; elle suggère que le meilleur plan d'action ne doit pas nécessairement comporter un ensemble de mesures à appliquer de manière uniforme à travers le monde, mais peut aussi avoir à être décomposé en plusieurs plans très spécifiques et de natures trés variées, s'appliquant aux diverses régions du monde.

II. CONCEVOIR UN PROGRAMME D'ACTION

Parlant pour l'ensemble de mes collègues économistes, je ne vais certes pas vous offrir un programme; mais je voudrais faire apparaître comment nous pouvons contribuer à la recherche d'un tel programme.

Quand ils traitent du choix de programmes, les économistes ont l'habitude de se situer alternativement à deux niveaux. Tantôt ils imaginent avoir vis-à-vis de la collectivité une liberté d'action limitée uniquement par des contraintes physiques; ni les institutions ni la structure sociale n'imposeraient alors de contraintes supplémentaires. Tantôt ils prennent en considération, du mieux possible, l'ensemble de toutes les contraintes qui effectivement limitent les choix.

Le premier niveau d'analyse apparaît utile parce qu'il permet de classer les questions et donc de les clarifier. On peut aussi entretenir l'espoir que dégager un programme qui soit le meilleur parmi ceux compatibles avec les contraintes physiques exercera un impact sur la conscience collective et influencera la transformation des institutions et des structures sociales de manière à ce qu'elles s'adaptent aux exigences du futur.

Quoiqu'il en soit, je vais me placer successivement à ces deux niveaux et faire d'abord comme si seules les contraintes physiques s'imposaient au développement économique du monde.

A. Le choix à l'intérieur des contraintes physiques

1. Une méthode pour la recherche d'un programme peut certes consister dans la construction d'un modèle qui représente du mieux possible les contraintes physiques et dans l'exploration de l'ensemble des solutions de ce modèle. Nous, économistes, n'avons évidemment aucune objection à cette démarche. En fait nous l'employons continuellement pour étudier les conditions de la croissance dans chacun de nos pays; cette démarche nous aide à clarifier et à quantifier les options, et donc à choisir entre elles.

Néanmoins nous devons bien être conscients de ce que construire un modèle ne suffit pas, cela pour au moins trois raisons:

— En premier lieu, et je rougirais devant vous à faire une telle remarque si elle n'avait pas été négligée dans le passé, il faut que le modèle représente correctement les contraintes, qu'il tienne compte pour cela de tout l'acquis des connaissances scientifiques. Dans le cas qui nous intéresse, cet acquis n'est pas négligeable; les économistes en particulier ont beaucoup travaillé pour rechercher comment l'ensemble des contraintes physiques pouvait au mieux être représenté au niveau global.
— En second lieu, l'exploration des modèles possibles doit être guidée par des principes de choix, eux-mêmes lucidement choisis et clairement explicités. Or pour les questions qui nous réunissent ici, ces principes ont beaucoup d'importance; je vais y revenir dans une minute.
— Enfin l'étude d'un modèle ne suffit pas, car les décisions à prendre se situent à un échelon beaucoup moins global que celui nécessairement retenu par le modèle; le modèle global n'est qu'un instrument parmi d'autres tout aussi nécessaires et se situant à d'autres niveaux, par exemple à celui de telle ou telle ressource particulièrement importante.

En somme, il y a bien des questions à regarder de près avant la construction d'un tel modèle, ou parallèlement à cette construction. Quand on procède à cet examen, on s'aperçoit que l'on peut déjà bien clarifier certaines questions.

2. Pour les problèmes touchant l'allocation des ressources, les économistes ont depuis longtemps l'habitude de distinguer deux préoccupations: celle de l'efficacité et celle de l'équité. Ils cherchent d'une part à proposer une utilisation efficace des ressources, c'est-à-dire à privilégier les emplois les plus utiles par rapport à ceux qui le sont moins. Ils cherchent aussi à orienter l'activité économique en fonction de certains principes de justice distributive.

Dans le contexte de notre congrès nous devons prendre conscience de ce que les considérations d'équité jouent un rôle très important. Elles ne sauraient être négligées pour les décisions courantes prises à l'intérieur de chaque pays, et le ralentissement de la croissance est susceptible d'y compliquer la réduction des inégalités. Mais surtout ces considérations doivent intervenir sur deux plans où elles sont particulièrement difficiles à appréhender: la justice dans la répartition des biens entre les régions du monde et la justice dans la répartition des biens entre les générations.

Je n'ai évidemment pas la possibilité de développer ici ces points, mais je voudrais faire valoir leur importance et signaler que les économistes y travaillent. Ils s'intéressent à la détermination des principes de choix; peut-être d'ailleurs n'ont-ils pas plus de qualification pour cela que les philosophes ou tous autres savants; mais l'importance de la question les oblige à la regarder de près. Ils vont même plus loin que les autres, en ce sens qu'ils étudient les conséquences de divers principes de choix sur la croissance économique qui sera retenue. Or cette étude apprend beaucoup; elle montre que l'intuition induit souvent en erreur sur la signification effective des principes adoptés a priori; elle aide ainsi par une démarche dialectique à progressivement mieux comprendre ce que ces principes signifient.

3. Quittant les question d'équité, je voudrais maintenant consacrer quelques instants à l'attitude qui convient vis-à-vis d'une des caractéristiques majeures des problèmes qui nous réunissent; je veux parler de leur énorme incertitude. Celle-ci intervient pour la

plupart des facteurs concernant la croissance économique future. Elle est si importante qu'on ne saurait la négliger, même en première approximation.

En face de cette incertitude les attitudes varient; car tous n'attribuent pas les mêmes probabilités aux diverses éventualités possibles et surtout les éthiques individuelles diffèrent quant à la mesure dans laquelle la collectivité humaine devrait accepter des sacrifices en vue de réduire les risques auxquels son développement futur est sujet. La majorité des économistes adopte cependant aujourd'hui la position suivante.

Il est possible que l'économie mondiale voit dans l'avenir s'accuser des raretés de natures diverses et qu'ainsi les conditions du développement subissent une mutation par rapport au dernier siècle écoulé au cours duquel, du fait du progrès scientifique et technique, les raretés ont eu dans l'ensemble tendance à s'atténuer. Devant ce risque, ils recommandent qu'une politique prudente soit adoptée pour la natalité, l'exploitation des ressources naturelles et la préservation de l'environnement.

Les choix économiques doivent privilégier, plus que par le passé, la qualité de la vie, les méthodes de production économisant les ressources rares et l'orientation des consommations vers les services ou les biens peu coûteux en ressources.

4. Pour mettre ces principes en application, point n'est besoin de les enserrer dans un modèle mondial. Il faut savoir les appliquer convenablement dans la gestion de chaque ressource et plus généralement dans toutes les décisions économiques.

Nous devons éviter l'erreur qui consisterait à paralyser de façon désordonnée l'activité de production, car ceci imposerait aux hommes, particulièrement aux plus pauvres, des sacrifices inutiles. On doit noter à ce sujet qu'une politique prudente pour l'exploitation de la planète ne signifie pas nécessairement qu'il faut s'interdire d'épuiser certaines réserves. L'humanité ne peut vivre sans consommer de ressources naturelles; un bon arbitrage entre les besoins présents et les besoins futurs peut très bien consister à utiliser aujourd'hui certains réserves pour accroître la productivité du travail des générations à venir.

B. Comment agir dans le monde tel qu'il est?

Les problèmes se compliquent considérablement quand on abandonne l'hypothèse commode d'une liberté d'action qui ne rencontrerait pas d'autres contraintes que celles du monde physique. Il m'est impossible de donner ici même une idée sommaire de l'ensemble des questions qui se posent alors aux économistes. Je me contenterai donc d'abord d'examiner brièvement les instruments grâce auxquels peut se réaliser l'adaptation de l'activité économique aux conditions changeantes du développement humain, puis d'attirer votre attention sur l'importance d'une prise en compte réaliste de la division du monde en grandes régions.

1. Il existe deux instruments principaux pour régler effectivement l'utilisation des ressources dans nos sociétés: les prix et les contrôles directs.

Les économistes ont beaucoup travaillé sur le rôle que jouent les prix et sur le fonctionnement des marchés; car eux seuls pouvaient le faire, alors que l'étude des contrôles et de la "gestion bureaucratique" intéresse tout autant d'autres chercheurs, les sociologues par exemple. Mais, contrairement à une opinion répandue, les économistes ne se considèrent pas comme des propagandistes du système des prix. Ils cherchent au contraire à déterminer comment combiner au mieux les prix et les contrôles directs; s'ils arrivent souvent à la conclusion que le fonctionnement des marchés doit jouer un rôle, c'est à la suite de leurs réflexions et non en raison d'une préférence dogmatique.

Leur attitude est au fond tout à fait semblable à celle qu'aurait chacun d'entre vous s'il s'imaginait investi de la responsabilité d'obtenir une réduction de la consommation d'énergie dans son pays: quels rationnements pourrait-il effectivement mettre en place? Quel rôle attribuerait-il aux relèvements de prix?

Depuis longtemps les économistes ont observé que les variations de prix constituaient souvent l'intermédiaire le plus efficace pour la réalisation des adaptations aux changements du contexte, et une réflexion personnelle sur l'exemple de l'énergie vous aidera sûrement à comprendre pourquoi il en est ainsi. Mais cet intermédiaire n'est pas toujours fiable et les "défaillances du système des prix" sont au centre de beaucoup de travaux de la science économique moderne. En fait nos recherches théoriques les plus abstraites et les plus approfondies ne visent pas, comme on le croit souvent, à la construction d'un modèle idéal dont l'élégance nous plairait, mais à l'étude fondamentale des difficultés qui peuvent être à l'origine des défaillances du marché.

Quand nous devons faire des recommandations pour telle ou telle question concernant l'organisation institutionnelle face à un problème de gestion des ressources, nous sommes le plus souvent amenés à procéder à un arbitrage délicat entre des difficultés opposées. Une certaine planification, des règlementations ou des directives quantitatives ont souvent leur place à côté de la police des marchés ou d'interventions agissant par l'intermédiaire des prix.

La perspective d'une éventuelle raréfaction des ressources conduira vraisemblablement à modifier les termes des arbitrages et à recommander un interventionnisme accru de la part des autorités publiques locales et nationales, ainsi qu'une intensification des accords internationaux.

2. Quand nous réfléchissons aux problèmes de la croissance nous ne pouvons nous satisfaire d'une vision purement mondiale, je l'ai déjà dit. Il faut que nous portions une attention particulière aux régions critiques dans lesquelles l'adéquation des ressources aux besoins risque de poser des problèmes particulièrement aigus. A lui seul, ce fait est de nature à changer considérablement les conclusions auxquelles peut conduire une réflexion traitant le monde comme un tout.

Je voudrais bien faire apparaître la difficulté, sans prétendre d'ailleurs proposer une solution. Pour cela je vais retenir l'hypothèse que, en vue de lutter contre l'éventualité d'une détresse en Asie, nous cherchions à proposer un "plan d'actions pour l'humanité" qui ne vise pas d'autre objectif et qui soit assez réaliste pour avoir une chance d'être suivi d'effet.

La plupart d'entre vous estimeront que cette dernière condition conduit à rejeter l'idée selon laquelle les divers pays du monde devraient intensifier leurs efforts pour produire en quantité suffisante les biens dont l'Asie peut avoir besoin et pour réduire corrélativement leur propre consommation. Raisonnons donc comme si les transferts internationaux ne devaient pas connaître l'augmentation considérable que supposerait un tel plan.

Certains peuvent penser à proposer un fort ralentissement de la croissance économique du monde industriel. Des ressources naturelles seraient ainsi conservées et pourraient éventuellement servir aux besoins asiatiques.

Mais, à la réflexion, ceci risque d'être une mauvaise proposition. Le développement économique de l'Asie est la meilleure garantie contre la détresse envisagée et il a toute chance de souffrir d'un ralentissement de la croissance du monde industriel; le pouvoir d'achat des pays asiatiques sera défavorisé par la diminution des ventes aux pays industriels et par la réduction vraisemblable des capitaux reçus d'eux; le protecti[illegible] pays industriels risque de se renforcer, ce qui paralysera les efforts d'in[illegible]

Je ne veux pas pousser plus avant cet exemple qui vise seulement à faire apparaître un aspect important des problèmes qui nous confrontent. Il montre bien les inconvénients qui pourraient résulter d'une recommandation trop simpliste aux termes de laquelle le ralentissement de la croissance des pays développés apparaît comme un objectif en soi.

Si je dois conclure, ce sera pour relever la complexité des problèmes non seulement scientifiques mais aussi socio-politiques que pose l'orientation de la croissance économique du monde. Nous avons été bien hardis de nous engager dans le projet qui nous réunit aujourd'hui.

REFERENCE

1. La science économique face aux problèmes de la croissance, pages 1 à 125 dans M. Marois (éd.), *Vers un plan d'action, pour l'humanité: Problèmes et perspectives*, Institut de la Vie, North-Holland, Amsterdam, 1974.

CONCLUSIONS

The group of economists meeting at the World Conference of the Institut de la Vie expressed their conclusions as follows:

1. Choices that will be open to the development of mankind depend on what are the reserves of natural resources, on what will be technical progress for implementing new methods of production, finally on the laws ruling the transformation of biological and ecological equilibria. About these conditions of future growth present scientific knowledge is subject to very wide margins of uncertainties.
2. The risk seems to exist that we shall see in the future a strengthening of various scarcities so that the conditions of economic development will experience a drastic change in comparison with the past hundred years during which, as a consequence of scientific and technical progress, scarcities tended as a whole to decrease.
3. Facing this risk one may recommend that a cautious policy be adopted with respect to natality, the management of resources, and preservation of the environment. Whether a substantial slowdown in the overall growth rate of world production will be required is not yet clear. Since the cost of such a slowdown, particularly for the poor countries, would be heavy, it is premature to favor it. We can, however, recommend the choice, more than in the past, of the quality of life and this may require a retardation in the growth of output of manufactured products, at least in the countries already industrialized.
4. In order to take due consideration of long-term requirements and to help quick adjustment to new conditions, the management of resources must know how best to combine the operation of markets, and the use of prices, with planning at the local, national and international levels. The actual combination of these instruments must not result from dogmatic preferences but from a particular examination of each case. It is clear, however, that new and more effective institutions of social planning will be needed.
5. Problems raised by the balance between resources and needs are likely to arise much less for the world as a whole than within some underdeveloped regions. The growth policy of other regions must be formed taking proper account of its consequences on these critical regions who may need markets for their products, financial loans, and gifts in kind. If it

happens, the retardation of industrial expansion in developed countries must not be realized at the cost of poor countries.

6. Progress of human conscience and solidarity more generally requires that the distribution of goods become more equitable within each country and among countries. In order to achieve these objectives, one ought to persuade the citizens of various nations that their long range interest recommends assistance to the poor, particularly to those of the underdeveloped world.

7. We urge economists to intensify their efforts to understand and foresee the implications of population growth and of the possible increasing scarcity of physical resources and energy, in cooperation with their colleagues in other disciplines. We need, on the one hand, factual studies on demand and supply of scarce materials, and, on the other hand, deep thinking on the functioning of institutions and on the desirable reform of economic organization.

DISCUSSION

ABRAMOVITZ: I should like to thank Professor Malinvaud on behalf of all of us for the very clear, very difficult general report which he has made and the exposition he has given us as to the general kinds of problems as economists we face: look at them. Now I should like to invite members of the group at large to pose any questions they may have, or make any statements they feel they would like to make at this time. These questions may arise out of Professor Malinvaud's own statements or may be independent of them. I should like to see a discussion as general and varied as possible.

CLOUD: I want to express my appreciation for Professor Malinvaud's remarks, particularly the cautionary approach the economists have taken and their concerns for equity among peoples and nations. I attended several of your discussions, and I was very much impressed by the attention you were paying to moral philosophy and equity. There are a number of comments I would like to make, but I will confine myself to talking briefly about substitute ability, a question or a matter in which Professor Malinvaud seems to place great reliance. I want to call your attention to three things about substitute ability. The first thing is that 86 or 50 of the 90 naturally occurring are already in economic use in the industrial nations and there is very little room for substitutability of new elements for old ones. The substitutability then comes primarily in the substitution of more abundant for less abundant elements or in the substitution on new materials that are created by materials science and technology. But there are several aspects of this too that must be taken into consideration. When one looks at what substitutability has done in the past it really has had very little effect in slowing down the rates of consumption of the elements substituted for. The substitution of plastics in containers. for instance, has barely affected the rate of increase in the use of glass, paper, aluminum, and

I think it should also be emphasized that when we consume more and more commodities, this does not necessarily mean that the *volume* in cubic meters or tons of commodities is increasing. In fact, the volume in tons or cubic meters may well be *falling*, because many commodities become smaller and smaller by the miniaturization. I think that when non-economists talk about indefinite growth, they often seem to think that the material content, for instance the *weight* or the *volume* of commodities, will rise indefinitely. That is not necessarily true. We may very well experience a *fall* in the weight and volume of materials because of the miniaturization and the substitutions on the production and consumption side, including shifts to services.

In summary, the range of substitutions is much larger than people usually realize. The conclusion is that the *exhaustible* resources of minerals, will, in fact, never really be exhausted because it would be too expensive to dig up all the high-cost resources from the earth.

CLOUD: I am not unaware of the realm of possibilities of substitutions, including substitutions of technologies and so on. The points I would emphasize are that every substitution made is one that you cannot make again that all substitutions consume some raw material, and that substitutions often lead to a lower level of efficiency. I have no doubt that we could invent some sort of an industrial economy that could run entirely on the really abundant and universal elements such as iron, aluminum, magnesium from the sea, and silicates. But what kind of an industrial economy would it be? It's a matter of choices, a matter of trade-offs. I think that most of us would agree that if we went to that we would lose quality in some, perhaps many, important areas—for instance in high-speed computers, communications systems, and other things. We really have to decide what the greater good is—the sustenance of a less populous high technology economy or a gradual movement to a lower and lower technology economy.

ABROMOVITZ: Thank you, did you want to say something else, Mr. Lindbeck?

LINDBECK: Just a small comment. I see no reason to move to a "low technology" economy, but rather to a *different* "high technology" economy, when relative scarcities change. I think the question is *not* a low or a high technology, but the *kind* of high technology we want to have to adjust to human needs and relative scarcities.

SAUVY: Mon observation voulait aller précisément dans le même sens que celle de M. Lindbeck. J'ai été frappé, dans ce colloque, et bien souvent ailleurs, de voir à quel point le mot croissance a conservé son sens un peu prestigieux, un peu magique, alors que la notion est devenue de plus en plus incertaine. L'ensemble du lot de richesses produites et comptabilisées comporte, en proportion, de moins en moins de matières et de plus en plus de services, dont la valeur est bien souvent conventionnelle. Cependant, dans le domaine matériel, nous restons dans le régime des prix et d'une large liberté d'initiative. Ce jeu libéral n'assure pas la solution optimale, parce qu'il n'amortit pas les ressources naturelles. Nous devrions constamment prévoir et pratiquer para suite, en quelque sorte, les prix de demain. Grâce à la "bienveillance" des Arabes, nous avons eu un commencement de changement de la notion même de croissance. Nous consommerions évidemment beaucoup moins de nature, en jouant aux échecs ou au bridge qu'en consommant directement un combustible fossile qui corrompt l'atmosphère. Mais, à ma connaissance, il n'y a non seulement pas d'application pratique, mais pas de bons modèles, avec une matrice appropriée qui puissent nous dire combien chaque produit consomme de nature. Munis de ces compte, nous pourrions non pas arrêter la croissance, ce qui n'a guère de sens, mais l'infléchir dans le sens d'une moindre consommation de nature. Sans me dissimuler les difficultés du calcul, je pense que nous devons le tenter, c'est le rôle propre des économistes. Les générations à venir pourront nous reprocher, dans vingt ou cinquante ans, de ne pas avoir rempli notre fonction.

HORVAT: I should like to provide some concrete information which would probably answer directly the three questions asked. When we talk about exhaustible minerals we primarily mean metals. As far as metals are concerned, the amount of metal which is contained in the earth crust down to 1000 metres apparently worked and are on the sea bed, is about several million times bigger than the quantities consumed currently. So for all practical purposes it is inexhaustible—it is without limit—and there is nothing to worry about there. The second question, or rather a statement which has just been made, is that whenever you have a substitution it is at a lower level of efficiency, is simply not true. The data we have—particularly data for the United States, which are the most complete ones—show that from the nineteenth century into the twentieth century the amount of capital for unit of output in mining has been decreasing constantly. It is clear that in the nineteenth century people were mining the rich ores; now they have to mine poor ore. Still, the technological problem has been so fast that it has really been running faster than the exhaustion of the minerals. The cost in terms of capital have been increasing. As Professor Lindbeck has pointed out, this is reflected in the changes of relative prices. Let me quote four prices of four leading minerals: again, this is in the United States, in the period 1925–70. In this half-century period the prices of aluminum have decreased by 55%, of lead by 6%, of zinc they have gone up by 3%, and of copper they have gone up by 90%. People usually quote copper as a leading example of a mineral that will be exhausted rather soon. That is why the price went up so much and that is why copper was replaced by aluminum, whose price went down so much. That is how the process of economic development and substitution goes on. From the point of view of information that we have, and from the point of view of the technological progress that has been known to us in the last century, there is really no point of worrying about the exhaustion of minerals in the world—at least not in the next century or so.

MEDOW: I was not able to participate in the proceedings of the economic meeting yesterday because I was involved in those of the modeling section. Several topics arose in that section that may also have been

discussed elsewhere. In particular I wonder if the following two difficulties, which are very real at the present time, were discussed by the economics group. First, in the case of evaluating the results of those experiments with computers that are programmed, not in terms of optimization techniques of the type familiar to neo-classical economics, but in terms of a different group of conceptional categories that are associated with cybernetics and systems analysis, is it possible for a verbal discussion which is not informed of the nature of the programs that were employed to come to the conclusions that you have mentioned? Secondly, is there not in the approaches of one or two of the better known models of this type. I mean systems oriented, simulation algorithism oriented, approaches that emphasize the complementarity of the relations and the presence of both destabilizing and stabilizing feedback loops for control purposes, rather than possibilities for substituting nearly everything for each other, as optimization models something fundamentally different from the neo-classical perception of economic dynamics, and something which is closer to the classical tradition of political economy than to the more recent models? These two issues, must, I think, be fully clarified before recommendations such as those of the economics section can be taken seriously.

ABRAMOVITZ: I think we had some difficulty here in understanding the central point you were making. I wonder whether you would not elaborate just a bit?

MEDOW: I have essentially two questions to ask, both of which stem from the fact that we are now dealing with models that are based not on short systems of mathematical equations that may be seen on paper, but with complex algorithmic models that are embedded in computer programs written in a variety of computer languages. But in addition some of these computer programs embody not principles of substitution for purposes of optimization but, generally speaking, principles of cybernetics and systems analysis. This means that they consider above all complementarities among elements and also disturbances in relation to normalize states and possibilities for this neutralization. There are two implications of this. One concerns methodology and there the nature of the problem is almost self-evident. The other concerns the nature of the processes being studied. In the course of its development economic thought was initially concerned with political economy with the production and distribution processes of the material infrastructure of society, not with substitution problems—this is a later development. Is there not a turn now in the works of computer models, in the area of computer models, back to political economy, to relations of complementarity, to problems that are more fundamental to the policy issues of our time than substitution problems? But how can it be asserted that this is not so without knowing much more about the computer programs being used?

MALINVAUD: Je peux essayer de répondre, mais je dois dire que, ayant été formé fondamentalement dans la tradition de Descartes, j'ai peine à réviser complètement les modes de raisonnement logique qui sont les miens. Ces modes de raisonnement logique me semblant appropriés pour traiter les problèmes que l'humanité rencontre. Je comprends tout à fait quue l'on me dise par exemple: "Vous surestimez les possibilités des substitutions": c'est une question de fait qui demande un examen précis. Mais je ne comprends pas que l'on me dise que les modes de formalisation avec lesquels nous travaillons sont fondamentalement inappropriés. Vous nous avez dit que l'économie politique à ses débuts n'était pas la science des substitutions, mais la science des complémentarités. C'est une mauvaise définition de l'économie politique; celle-ci étudie l'utilisation des ressources rares pour la satisfaction des besoins de l'humanité. Les premiers hommes qui ont examiné cette question ont fait jouer relativement peu les substitutions (dans l'économie politique classique, la substitution des terres les plus pauvres aux terres les plus riches complètement exploitées a cependant joué un grand rôle). Depuis, nous avons été conduits à attribuer de l'importance à ces substitutions. Mais fondamentalement, l'économie politique n'a pas changé de vocation. Il se peut qu'effectivement, dans la phase nouvelle que nous abordons, les substitutions soient appelées à ne plus jouer autant de rôles qu'elles en ont joué dans les siècles passés. C'est l'information factuelle qui nous renseignera à ce sujet. Peu importe que l'on fabrique des langages informatiques en communication les uns avec les autres. Ces langages ne généreront pas spontanément les réponses que l'humanité attend aux difficiles problèmes qu'elle

ment de 28 millions de données psychologiques, économiques et analytiques, a fait apparaître que ce pays, abondamment nourri en calories alimentaires, abondant en acier utilisé, est atteint d'une carence pour 50% de sa population, la carence en fer de l'hémoglobine du sang. Il y a là une contradiction étonnante entre votre démarche, qui s'exprime par tonnes et la démarche physiologique qui s'exprime en milligrammes par litre de sang. N'y a-t-il pas dans l'Institut de la Vie et dans la démarche qui nous anime ici, une espèce de contradiction qu'il faut souligner et qui, peut-être, expliquerait certains malaises dans les conversations que nous pouvons avoir entre nous, entre économistes et biologistes.

BROWN: It is a dangerous, and I believe a gross oversimplification to say that just because there are x billions of tons of elemental materials in the crust of the earth that we need not worry for the next century. This afternoon we are going to discuss this in some detail, but I should just like to say at the present time that while it is true that one can demonstrate mathematically and chemically that man could, if he were forced, live off the ordinary rocks of the earth's crust. While this is true, it depends upon two assumptions: the first, that he has adequate technology, and the second that he has adequate energy. It is basically a question of how much one pours into the system. Clearly, it takes more energy to get copper out of an ore that contains 0.2% copper than it does to get copper out of an ore that contains 1% copper. Superimposed upon that, as we go to lower and lower grade ores the environmental problems become magnified and if the environmental problems are to be rectified that in turn necessitates the expenditure of still more energy. So basically it is a problem of thermodynamics and it is a problem of technological development. It is by no means clear that technology is going to keep up with the race. It is quite true that our technological achievements have been considerable in the past. It is dangerous—as most of us know—to assume that the future course of technological change will duplicate that of the past. Thank you.

PIORE: I guess my best identification is still IBM, even though I do have offices at Rockefeller University. I should like to take a different point of view than my two American colleagues from the National Academy. We might as well debate here as well as in Washington. I think one has to be very careful in degrading the technological changes that will occur. Many of them will occur and will be very profound. I guess the greatest saver of energy was the invention of the transistor. Just count the number of radio sets and television sets in each house. Just make some numbers and calculate the number of the tubes by the transistor. I used the transistor as a familiar example, but the whole electronic and electrical industry for the last decade has been reducing the size of equipment. This reduction in size, these technical innovations, always reduce the power consumption. I think the technological change has not saturated—it just does not give credit to all the young, bright, imaginative people who exist. They will invent and invent and invent. Do not sell the engineering fraternity short.

LEWIS: The best identification, I think, is atomic energy. I would just like to point out something that was in the paper I presented yesterday that won't have reached these other people, that in Ontario electricity is now delivered to Toronto more cheaply from their nuclear plants than from a hydroplant transmitted 250 miles through aluminum conductors. I point this out as an example of an advance in technology that is only just beginning. But it is there, it is established on a significant scale—2 million kW. As far as I can see there is a lot more wrong—I should certainly agree that technology is offering us a great promise in substitution.

ABRAMOVITZ: I think it is a good idea if I try to introduce another note into this discussion. It is one thing to talk about the possibilities from the physical side, of proper adaptation and response and adjustment to a possible growth of shortages, a possible increase of shortages or of scarcities of particular kinds of resources, or of environmental deterioration and so on. It is another thing to say that the market will give us the proper signals for making the kinds of responses or adjustments that are needed. I should like therefore to call on one of my colleagues, Professor James Meade of Cambridge, to talk about these questions from his own point of view.

MEADE: I suppose I am considered by my colleagues to be on the pessimistic side, although in a rather refined way which I will try to indicate before I talk on the question which has been put to me by the Chairman. It is unnecessary for me to stress, after Professor Malinvaud's introduction, how much attention we should pay to the uncertainty of future events. The rate of population growth, the rate of technological change, and the nature and scale of productive operations is now such that there is a chance that we shall hit the limits to growth with catastrophic results before we are able to make the necessary adjustments. I do not myself believe that the probability of this is very high. I accept all my colleagues' stress on the possibilities of substitution. I am greatly impressed by those technologists who say that there are a lot of inventive young men who are dealing with these problems and that technology will probably play an enormous part in solving the problem. All I am saying is that there is a chance that things will go wrong. There are two things on which economists differ when they look at a problem of this kind. One is the probability they give the chances of it going wrong and the other is the extent to which they are gamblers of risk averters. I am a "playing-safe man" and I always have been; and for that reason I raise the question: What should be the change in our economic institution if we want to play safe? Economists have always seen great efficiencies in the price mechanism as signals for substitution and action. I am known among my professional colleagues as an admirer and proponent of the market and the price mechanism. But I am now going to play the other role of talking about its deficiencies. We economists have always believed that there are many

reasons why the government should not leave everything to the market and that there are many things it should do itself in the economic sphere. But ought we, in view of the threat of doom and a desire to play safe, to change our attitude towards the degree of reliance we put on the market and on prices as compared to the degree of reliance which we put on government intervention, controls, planning, and so on? I will merely enumerate very quickly five ways in which playing safe to meet the threat of doom does alter a bit the balance between reliance on markets and on governmental controls. The first is that refined sophisticated work is making it more and more clear to economists that the price mechanism is not a good signaling device for dealing with the future. For this purpose, it needs supplementation. Theoretically, if the price mechanism was to deal with the future you would have to be able to deal now in a forward market for every commodity for every future period, for every future major contingency. This is absolutely impossible, of course, and there are very good reasons why this range of future markets cannot exist. Therefore, if we are more troubled about what the future may hold in store for us, we have got to put more stress on what I would call governmental indicative planning. There are all sorts of approaches to this. There is the approach of construction of dynamic models based on the inrelationships between economic variables that one thinks from empirial evidence are the most probable ones and then seeing what such a model will lead to in various future contingencies. There are other useful forms of action, one of which certainly requires governmental action and is what is usually meant by indicative planning. In its simplest form it is a very grubby form of action, but it can be very important. You simply get the steel producers together with the steel users and you ask the steel users how much steel they are likely to want, and you ask the steel producers how much steel they will be likely to be producing in 10 years' time, and you see a great divergence between the two, you have done something very crudely which a theoretical forward market would have done very beautifully. The second measure which I think the government might take in a program to "play safe" in view of the threat of doom is to promote research and development for the encouragement of the new technologies that may be necessary if the pessimistic outcome comes about. The third set of measure which I have in mind is that one should shift the emphasis a bit in the devising of economic policies in such a way as to put rather more emphasis on redistribution of wealth and rather less on crude economic growth. Think more about reducing poverty by redistribution and a little bit less about just increasing the output so that everybody can be better off. Redistribution has three aspects, of course, as Professor Malinvaud himself mentioned in his introductory remarks: first of all, distribution between the rich and the poor of anyone generation in anyone country; secondly, distribution between the rich and poor countries, which is perhaps the world's most important problem; and, thirdly, redistribution between the generations. If we think that future generations will be poorer than us, then that is an argument for saving rather more, perhaps through budget surpluses, than we would perhaps otherwise do. I come next to the fourth sphere for government action to cope with what I personally think is the greatest problem of the lot, namely the population explosion. But I fear that I have no precise message to give to anybody about what type of governmental action will successfully cause a reduction in fertility. The fifth and last main sphere for increased governmental planning and control that I would mention is governmental action designed to cope with what economists call externalities, such as pollution where one agent doing something has a serious effect on other people, the cost of which does not come into the price mechanism. The polluter does not have to pay for the damage he does. There is a whole range of well-known pollutions of the environment of this kind; and it is absolutely essential—if one takes the threat of doom rather more seriously—that one should put more emphasis on government controls against this sort of thing. I would like to sum up in the following way. Having spoken in this way about the deficiencies of the mechanism, I have not lost my faith in the market. We should start by doing all we can to make the price system work effectively. For example, in the case of exhaustible raw materials we should get such a rise in price that people have an incentive to economize. The market should be the base. Moreover, and this is a point Professor Lindbeck stresses very much and with which I entirely agree, I think governments do an awful lot of intervention on a lot of little pernickety things that are not of very much importance. They should stop doing that and concentrate on the important cases where governmental action is essential. Let us always remember that there are fools and knaves and all sorts of shortsighted people among bureaucrats as well as among businessmen and among market operators. We are not able to replace the market mechanism with the Perfect Platonic guardians which we would like to have. I think we should get rid of as much inessential intervention as possible. But there are some governmental interventions which are justified for a policy of "playing safe" to meet the threat of doom: indicative planning, the stimulation of the new technologies that may be necessary if things go wrong, the control of pollution,and putting more emphasis on redistribution rather than on growth. Finally, there are two things the implications of which I find most difficult and distasteful: the reduction of fertility and the moulding of peoples' tastes so that they like the quiet, gentle life rather than the straining for higher and higher levels of material production.

TINBERGEN: The sort of message I would like to formulate is, I might say, the result of many discussions I had with my brother, Niko, who is a biologist and who is much more pessimistic about growth than are economists. But I understand that he is representing a fairly important group among biologists, or ecologists, as they are now called. I just want to recall to you some of the consequences I as an economist tried to draw from the message I got through. So I am not saying that necessarily I would be in agreement with everything I am going to say now myself, but it is an attempt to formulate something that, as far as I can see, is an

important view and might be underrepresented in this congress. His way of looking at the future production of food is one of extreme precaution. Ecologists feel, for instance, that the degeneration of certain species of plants that have been selected very thoroughly on productivity, also the degeneration of the soil by pollution —and for that matter of the oceans, where everything finally of course arrives—creates a need to maintain a sort of reserve of genes in order to renew plants at the moment they are degenerating. All that together makes them believe that it is absolutely necessary to keep within limits the future growth of food. Moreover, they state correctly that in the last 20 years the annual rate on food production, if you take the trend, has not been more than 2%. There was a time when F.A.O. in its World Indicative Plan, took 4% as a possibility, but they have come back, I think, from that figure. So I took 3% as the possibility of annual food production increase. I extended this over 40 years—just to see what the consequences would be for a number of key variables in the process of human development adding one more element that was mentioned already this morning and was shared by many of us in the group of economists, namely that very high priority has to be given to the development of poor countries, since the level of life there is so inhumanely low that, first of all, for human reasons, also for political reasons, we cannot leave it there but have to very much accelerate their growth in production per capita and consumption per capita. Now making a choice there (which is, of course, arbitrary) that it would be necessary to increase their consumption per capita on the average over the 40-year period by 5% per annum, which would mean increasing it by almost eightfold, I came to the conclusion that if such a thing is absolutely necessary then the manoeuvering for, on the one hand, the increase in population and, on the other hand, the growth of the rich countries, is extremely limited. As one possible picture that would satisfy the conditions that I just formulated, I can see one where over the same period of 40 years the average rate of growth of income per capita for the rich countries had to be 1.7%—half of what it is now—which you could interpret as going down from the present level to zero level, 40 years from now. Even if you assume this, the conclusion must be that the numbers of people that can be fed according to this scheme will also have very severe limits and that therefore the reduction of population increase must be an important part of any policy that plays it safe—to use my neighbor's language—a preference which I share. You know, of course, that in Bucharest at the population conference, the suspicion with the developing countries has been all the time that we, from the rich countries, wanted to "impose" on them the reduction of their population growth, and they do not like this idea. I can understand this feeling. So I think that if there is a need for a deceleration of population growth, that this deceleration should be shared equally between the poorer countries and the richer countries. In order not to make my intervention too long, if you calculate the deceleration needed it would be —1.1% per annum in comparison to what it was in 1960–70. This leads to the conclusion that the rich countries, according to this scheme, have to be back on the 1970 population in about 40 years from now and that the poor countries could continue to grow at the decelerated rates in the average, over the whole period of 1.5%, meaning that they would have to tone down the present rate of 2.6% to about 0% to the end of the period. Of course there could be also a differentiation made between countries. You could simply apply the —1.1% to each country and then arrive at very different figures for different countries—diversification is not excluded at all here—but it would perhaps be a formula to find agreement where there was no agreement in Bucharest. There are two things I would like to repeat: (1) we have to give the biologists some time to find out—it is a much more complicated science than most of the other sciences that are represented here—whether indeed the dangers are as large as they now intuitively feel. But (2) we have to be careful at the same time. We have to be aware of the extreme importance of slowing down the population growth and we have not to forget the main thing: the enormous difference in well-being between the developing world and the developed world and the necessity to overcome this difference in a reasonable period. I know that what I have said is completely unacceptable to most politicians of Western countries. But I am not sure whether we should give in to those politicians: perhaps it would not be wiser for them to learn something from this way of thinking.

ABRAMOVITZ: We have had a number of different issues put before us now and I am not sure exactly how to conduct the meeting in the most orderly way. There were at least two of our members whom I failed to recognize this morning and who I assume want to revert to questions which arose at an earlier point in the discussion. I should like to give them a chance to talk first and then perhaps return to questions which arise out of the statements made by Professor Meade and now by Professor Tinbergen. I shall call first on Mr. Jantsch.

JANTSCH: I should like to get a reaction from the panel on a basic dilemma—what seems to me to be a basic dilemma—which has been bothering me for quite a while and which borders also on the issue of institutional change which has been evoked here in the morning and on some of the other issues which were discussed. That is that the economic institutions as we know them today in our highly industrialized countries are geared more or less to maximizing the criteria of efficiency and productivity. At the same time we—at least in the Western countries—try to retain as much as possible, the liberal dream. Professor Meade wants to retain rather much of it, other economists maybe less. We are very hesitant to leave behind the beautiful promises of individual freedom which this dream holds. It seems to me that the liberal dream in terms of systems can be found realized, for example, in natural ecological systems without human intervention, where a kind of self-regulation works and keeps the system viable. But, and this is a point, by precisely *not* maximizing productivity and efficiency. Nature is actually very unproductive and inefficient when it comes to systems.

It is only the individual bio-organisms which try to optimize their own efficiency of survival. We have also in human society a large degree of self-regulation when these human societies are at the low technological level, in particular in the areas of food and health technologies. There, in fact, the high rate of infant mortality and famine take care of the systems in a way which we from the Western countries denounce as being undignified for man. So we are again in a dilemma. It seems to me that the criteria of efficiency and productivity go together with the optimization of individualism, and as we are moving now into a time, and this is much the general theme of this conference I believe, when we have to recognize the interests of human systems or of mankind in a planetary or even in a species-oriented way, it seems to me that the exaggerated interest focused on productivity and efficiency ought to be placed on other criteria or ought to be de-emphasized in such a way that other criteria can come into play. My question is: Does a panel of eminent economists see institutional change also in this light, i.e. as change of the criteria by which institutions have operated so far and as bringing into play other criteria, something which makes the human world at the same time go away from the interest on the individual and go toward what Churchmann calls an ethics of whole systems.

CHAKRAVARTY: I think that the question that has just now been posed to us is of extraordinary importance. I think that the group of economists who did meet did discuss this problem—maybe not exactly in the same terms. I thought the message that Professor Tinbergen has just now communicated also refers to the same class of issues. I think it is important for us to recognize that we are not looking for merely self-regulating systems. We are also trying to regulate them in a certain manner which we consider to be consistent with human dignity. Of course, what constitutes human dignity is certainly a matter of value judgements, but I believe there is a considerable consensus on recognizing what constitutes the essence of human dignity. It is clear that in order to do that we have to think in terms which are not purely naturalistic. We have to think in terms of institutional and other modes of adaptive behavior. It is also clear that these conditions may have to be different in different parts of the world. When Professor Tinbergen spoke of the need for accelerating growth in the developing countries and a conscious decision to decelerate growth in the developed part of the world, when he talked of reducing the rate of fertility and slowing down the population growth in the world in the whole, maybe at different rates in different parts of the world, he was presumably talking about bringing about a kind of system, a kind of regime which would be more consistent with human dignity and would take us out of the dilemma that had been mentioned. I personally think—and I think this is a view shared by many of us—that economists, have traditionally emphasized market-based modes of adaptation, perhaps too much in several directions as Professor Meade has indicated —even though he is a liberal, he is willing to see the limitations of the traditional liberal arguments. I would go a little further. I would say that the market-based methods, if they have to be pursued in isolation or have to be pursued only in moderate doses, might not take us out of the difficulty. In fact, as far as the developing countries are concerned—about which I am entitled to speak a little more confidently—this will not solve the problem either of the population growth which is an extremely important one or the problem of improving the standard of living of the vast masses of people. I will illustrate my point very briefly because I do not want to take too much time. Basically the problem with the developing countries is the problem of imbalance between the stock of reproducible capital and the number of human beings who happen to be there at a given point of time. This is by and large the situation, although it varies from country to country. This results both in a very low level of income per capital as well as in a highly inequitable distribution of income. This situation is getting continuously more difficult for certain parts of the world at least as a result of rapid population growth which is not matched with a corresponding growth in production. If we have to get out of the difficulties I think we need to recognize two things: that the stock of reproducible capital in these countries must increase sufficiently fast and, secondly, that the growth of population has to be consciously regulated in a manner which is consistent with what I call human dignity. How do we do that? I think there are two problems here. One is if you allow human beings to be employed according to the normal market criterion, then you would find, for example, vast masses of unemployed who would not really be able to make a living and would constitute merely a hindrance. But if you do organize consciously the deployment of labour in rural areas, such as in a country like India or Bangladesh, then certainly you can do a great deal more with them than you would do if everything is to be regulated by the market criterion. Similarly, if you really want to increase the rate of savings through the market method, this will have to be done by considerable accentuation of inequalities in the generation of private incomes which will not only be ethically improper but may well pose problems for future development. In both these cases it is necessary to intervene in a socially purposeful manner. In terms of generating a distribution of income and channelizing the incremental flow in such a manner as to satisfy the requirement of increased savings and the requirement of deploying human beings more efficiently, I would go one step further. Even if we want to reduce the growth of population, the method that you need to adopt in a large number of cases would consist in the reduction of infant mortality, making more health care available so that people really feel more secure, have social security arrangements which is not currently available, and take steps for modernization of agriculture and other occupations leading to perception of economic opportunities which lead people to voluntarily adopt smaller family sizes. In each of these cases there is a close interdependence between economic changes, on the one hand, and general socio-demographic developments, on the other. In fact, if we adopt the above approach we can bring about an accelerated demographic

transition. I may also just briefly add that whilst I think the bulk of the responsibilities will have to be borne by the developing countries themselves in bringing about an acceleration in the growth rate, purposive international action can be a help. In this context I think the problem of trade and optimal division of labor over time will play an important role and which, I believe, can contribute substantially to the solution of the problem. It would also be very useful if the instability which characterizes farm product prices as also the prices of basic intermediates—as, for example, with fertilizer and so on—is minimized. So that the kinds of problems that developing countries subject to population pressure experience from time to time in times of scarcities of food, leading to inflation and certain other irreversible changes, can be mitigated. If there is a conscious international attempt at evolving an international economic program of action along these particular lines, and if this could be supplemented by international transfer of financial resources in areas which are important and in quantities which are important enough to add sizeably to their domestic efforts, it is possible to think of a situation where it would be possible to recognize the basic limitations to the world as a whole in terms of possible resource exhaustion and at the same time create a situation which would really be self-regulating—not in a mechanical sense or even in the sense of the mere reproduction of human species, but in a sense consistent with human dignity.

SHUBIK: I wish to make some comments on Professor Meade's observations on the role of economists and the role of markets. I think it is extremely important to distinguish the differences among *control*, *advice*, and *understanding*. It is my belief that most economists neither like to be in positions of control nor are very competent in those positions of control. It is furthermore my belief that in general the role of understanding is frequently misunderstood in the design of control mechanisms for human systems. I personally believe that economists have extremely bad understanding of many economic phenomena. However, I also believe that they have better understanding of these economic phenomena than most non-economists. The connection between understanding and control is nowhere near as strong as most people applying for grants for research make it out to be. This being the case, I suspect that the optimal role of economists in the sort of processes we have been discussing is as advisors. I think they are perfectly capable of giving reasonable advice, especially if they do not blind themselves by believing that their advice is based on the deep understanding of theories they do not have.

I would now like to comment on markets. I personally am an advocate of the use of markets whenever one can. I also believe that there is no such thing as *the* market, that there are many highly different institutions that reflect market processes. I also believe that most economists do not understand this. It has been my observation that most economists neither understand how most markets operate nor are capable of operating them. I find that many economists are not particularly capable of dealing with their own personal economic problems because they do not have the slightest idea of how markets work. They usually do not know how they clear, they do not know what the institutional forms are, and they do not care about the information content in these markets.

Furthermore, there has been a very interesting split in the economics profession. A few institutionalists who do not understand how markets work have been banned to special institutions and universities where they do not interfere with *reine Wissenschaft*. Pure theory as it is currently taught must be much more general than institutional studies—hence it cannot be bothered with little details like how a check clears; or exactly how fiat money get into a society or out of a society; or how curious instruments such as contracts work. Having said this, I would like to suggest that the central body of microeconomic theory which is meant to relate to the market has been designed to provide a spurious non-institutional general theory. It has the property that it is independent of mass market phenomena, as you can see by reading the excellent work by Arrow and Debreu. It does not matter how many individuals there are in the market because our economic theory is independent of the number of individuals in a market. The theory was designed to disregard all information conditions. This was done by implicitly symmetrizing the information conditions in such a way that they do not appear explicitly. Some of you are aware of certain works like Radner's, and I could mention others—which show where the information difficulties appear.

I would like to suggest that the question Professor Meadows was trying to raise (although I by no means necessarily agree with him) is a valid question. The question of Professor Jantsch was also a valid question. I want to try to point out why these were valid questions. Current economic theory is an incompletely defined system. It is precisely where that system is completely defined that the inconvenient questions that these gentlemen were raising come in. The incomplete definition can be seen when we look around the world and observe, for instance, that accounting systems exist. We observe that contracts exist. We observe that financial institutions exist. We also observe that financial institutions and governmental planning institutions are clearly the carriers of the economic process of society. They are not only the carriers but frequently provide the interfaces with non-economic processes such as political processes. I believe that it is the responsibility of the economist to be able to graft the financial and planning structure of society into their economic dynamics so that in those theories they can play the role of a neutral and informational network that they quite clearly play in the real world.

JASKE: I am an engineer. I have devoted my entire career to the development of nuclear energy from the days of the war. In listening to what I have heard today—up until Professor Shubik made his very brilliant observations—I noted a lack of the coverage of the detail that he so profoundly expressed. As a

practical man (and most engineers have to be practical) we live in a world where the free market exists in a very transient way. We face the market when we are evaluating future investment and facilities. But once these facilities are built up it appears to me that present economic theory fails to recognize the long-term nature of the capital structure of past investments. In pronouncing the degree to which inflation should or should not be permitted to exist, economists in no way seem to be able to evaluate the effects of this on the extremely large investment in public facilities which are amortized over periods of time from 30 to as much as 100 years. As a result of this, the prices of public services which emanate from long-term investment in public facilities, notably power facilities, sewage works, and water works, become systematically underpriced because there seemingly is no way for the economic theorists or the system to adjust the constitutional constraints and the value of these services upwards to meet ongoing market conditions. We have these curious anomalies of aluminum becoming cheaper in price simply because the power industries of most countries are subsidized by energy policies which do not reflect the market but purely political or social conditions. One of our colleagues addressed himself to the point of adaptive innovation. It is interesting that he comes from a company which is notably prominent for the short-term nature of their innovation. It is my personal belief that on-going society will have to improve its sophistication and, I hope, totally endorse his view. However, we engineers are frustrated almost constantly by financial institutions which really limit the creativity and capability of engineers and scientists working together toward innovative solutions. I would urge this conference—and particularly economists—to search their souls for some way to evaluate the existing capital goods in the world in a way which more truly reflects the need for setting aside some means by which innovative and creative solutions can be financed without having constantly to be told that it is going to take 10 or 15 years to do this and we cannot afford that and we have to prioritize this. In a way we close the options which are so desperately needed to solve the problems of mankind.

ABRAMOVITZ: It is clear we appreciate the help we are getting from speakers who have spoken recently. The panel is gradually gathering itself together to make some response to them. I shall call on Mr. Meade first and then on Mr. Chenery who want to address themselves to some of the questions raised by Mr. Shubik and the last speaker.

MEADE: My comments on what Professor Shubik said are very brief. I strongly agree with him about the limitations of economists, understanding of and ability to control economic events. We do not know very much, though I think we understand more than others about the economic system. I really agree with all that. The point I wanted to make refers to the second part of what he said. I think what he said may have given a wrong and exaggerated impression to some of the non-economists here of the extent to which the economists have neglected to study the way in which actual institutions and particular markets work in order to represent these properly in their models of the complete economic system. It is true, I think, that the institutional studies of economists are rather split up; there are labour economists and banking economists and so on. But I think that is rather natural. My thoughts turn to two of my colleagues when I was at the London School of Economists. Professor Phelps Brown devoted years and years to the study of the way in which wages are actually determined and to getting to know the way trade unions work and employers' federations work and so on. Professor Sayers did similar work in the field of banking institutions. But these were men who also had a general economic training and knew very well what economic analysis was about. I think that it would be false to give the impression that their thoughts are not incorporated to a good extent into the way general economists think. But at the same time there is a place for the generalizer like myself who does not know in detail how markets work, but hearing what Professors Phelps Brown and Sayers have to say, tries to think of the system as a whole. I do not think the separation of activities are as bad as Professor Shubik made out. I would just like to add one thing. There have been economists who have really been good at understanding markets and how they operate. My hero, Maynard Keynes, really knew from experience how markets worked; and though he was a quite exceptional case the divorce between economists and people who can operate in markets is not quite as complete as Professor Shubik suggests.

CHENERY: I sympathize with the attack on the regulation of power except I think the target is wrong. Power rates are not regulated by economists; they are regulated by politicians in most countries. In fact it is the regulation on the wrong principles which leads to the condition which you described, not only in nuclear power but in most forms of energy which have long gestation periods and where we need to be reacting to the conditions of the future. In fact, at least in the United States, our regulatory system is designed to react to the conditions in the past. Primarily there is a conflict between two aims of social good. One is the prevention of monopoly profits on which most of our utility regulation is based. The other is to have a sufficient supply of energy in the future. So far we have not devised a regulatory system or staffed it with people who have the second objective. The Federal Power Commission is based on the first principle and has been woefully inadequate in having foresight as to the prospective scarcity of natural gas, of oil, or any of the other things which the energy group will be telling us about. So that the prices that are set are clearly out of line—let alone the future prices, but also the present prices. This has nothing to do with economics; this has to do with the lack of the use of economics. I think it is clear in the energy field which is somewhat special in this discussion of resources. Among the resources which we talk about you can substitute almost all the other things, but energy substitutes only with energy. So we need a system which looks at the energy sources and the desirable alternatives and stimulates investment 10, 15, and 20 years ahead, as you pointed

out. This is not a system which can be based on the past costs, which the present sys not replace the equipment let alone stimulate production of new equipment, but ra signals. If Professor Meade has elaborated his full list of failures of the market, it is the economies of scale, technological uncertainty, and so forth which makes the m area. I think what we need is better economics, not that economists do not understand th understand the problem quite well. Their advice just is not followed.

PAILLAT: J'annonce la couleur: je ramènerai l'homme dans le débat. J'intervie mentaires faits par M. Tinbergen tout à l'heure. Il a mentionné la conférence de B figure au programme de ces réunions, mais vous me permettrez d'en toucher un m non pas comme un membre élevé des Nations Unies. M. Tinbergen a souhaité, compris, que les pays industrialisés, les pays développés, donnent l'exemple en ma croissance de leur population. C'est déjà fait! C'est déjà très largement en cours et, les Pays-Bas, qui avait la natalité la plus élevée d'Europe Occidentale, la chute du tau impressionnante, on pourrait presque la suivre à l'oeil nu. En ce qui concerne l'A taux de reproduction n'est plus assuré; en ce qui concerne l'Europe Orientale, vous le le savoir, le taux de natalité est faible, et même dans la partie européenne on observe exactement le même phénomène. Ne parlons pas, si ce n'est pour l'aneco natalité dans le Québec qui, jusque-là, se distinguait par un comportement particuli industrialisés, de ce côté-là, il n'y a pas beaucoup d'inquiétude, si ce n'est quant à structure de la population qui nécessairement s'ensuivra. Il faut bien savoir par exem citer le Japon, qui est un laboratoire vivant—que la proportion des personnes âgées, la santé, va tout de même y tripler en cinquante ans. Ce qui amènera nécessairement de la population, aussi bien de la population active que de la population inactive, devrait tenir une certaine place dans l'analyse économique et dans la prévision. Dans d'être légèrement en désaccord avec M. Malinvaud: peut-être qu'à vingt ans les prévi sont mauvaises, et on nous en a donné d'excellents exemples, mais à moyen terme en sont suffisamment bonnes pour être opératoires. En ce qui concerne les pays en voie justement c'est là où la conférence de Bucarest a été extrêmement intéressante—l'éch des campagnes de limitation de naissances n'a pas encoré été bien expliqué, mais il tant qu'un développement économique et social au moins élémentaire n'aura pas eu li que les gens de ces pays envisageront de limiter leur natalité, parce qu'ils n'ont finalem directe. On ne leur offre rien en échange. Les représentants des pays en voie de dévelop ceux de l'Algérie, ont été très clairs sur ce sujet M. Rockefeller—je veux dire le frère Etats-Unis—a bien dit lui-même qu'il avait compris après de longues années d'err pas placer la planification familiale en dehors du contexte du développement écono ce que les pays du Tiers-Monde ent soutenu, c'est qu'il fallait commencer par ce déclencher cet autre. Parce que finalement, il faut être conscient, et dans leurs propo ce qui est le problème à l'heure actuelle, notamment, ce n'est pas tellement le nombre de dont ces hommes consomment des ressources dont on nous rappelle, à juste titre, même relativement limitées. La consommation des Européens ou des Américains certains domaines de l'ordre de vingt ou trente fois supérieure à celle de beaucou conséquent, même une diminution de leur population n'aurait qu'une incidence e l'utilisation des ressources appropriées ou appropriables pour reprendre la terminol Je souligne aussi tout de suite, et je termine là-dessus, que les phénomènes démog d'inertie et que même dans les pays où les efforts les plus remarquables ont été acc limitation de la population, on ne peut espérer arriver à la croissance zéro dont tout bout d'un laps de temps qui peut atteindre deux générations. Autrement dit, les 3 supplémentaires auxquels la terre doit s'attendre d'ici l'an 2000 (2000 étant juste po inéluctables. Et je termine par une note qui disons pourrait nous intéresser tous: il impressionnant, semble-t-il, je dis cela avec réserve, de limitation progressive de la crois dans un processus intégré, c'est le cas de la Chine. Malheureusement la Chine est tel seignements de cet ordre que nous sommes encore largement livrés au jeu des conject soient-elles. Merci.

LINDBECK: Just two small points. As an economist I quite often have the feeling economists are blamed for the state of the world. I must say that this is slightly unf do not think economists have *created* many institutions and conditions. I do not thin very many policies either. What we are doing, of course, is *analyzing* the state of the w term perspectives, where uncertainties dominate, is exceedingly difficult. We also oc which is, as I understand it, very seldom followed. I think it is important to keep th economic analyses and the state of the world.

rate in developed countries goes down, this hurts the growth rate in the less-developed countries because their exports fall when they lose markets in the West. Also the protectionism in the West tends to increase when growth rates go down. We could also add that the ability and willingness to transfer resources to the less-developed countries will most likely fall if total resources stop growing in the developed world. So, personally, I do not think that Tinbergen's scenario is a consistent one, i.e. to combine, in the coming decades, a slower growth rate in the developed countries with a speedier one in the less-developed.

TINBERGEN: Yes, I shall make a few comments because I think it is everybody's good right here to deviate from someone else's opinion. But one misunderstanding I think in the reaction of my colleague Lindbeck with whom I usually completely agree, might be that I have mentioned figures of averages for the whole period, the idea being that we would start off with the present figures and only gradually, of course, change them. In the first period, that means that the growth of the developed countries would not change so very much, not even in that scheme. They would therefore still be able to serve as markets for the developing countries. But gradually industries have to be shifted, I think, and that might make it possible for the later phases of the period to the developing countries to grow on their own forces. I think that is sufficient for the moment. To have additional details, we had better do it by correspondence with anyone interested.

COULOMB: Je ne suis pas économiste et ne vais pas prendre parti dans ce qui a été dit, mais je pense avec quelque inquiétude aux personnes qui auront à se pencher sur ce que l'on a appelé des résolutions, disons sur les avis finaux que pourra comporter cette conférence. Dans tout ce qui a été dit jusqu'à présent, ce sur quoi une majorité pourrait être d'accord ce sont quelques idées très simples; elles devraient être extraites, par quelqu'un du groupe des économistes, de ce qui s'est dit ce matin. Dans l'exposé de M. Malinvaud par exemple, il y a la nécessité de concilier l'efficacité et l'équité, d'être prudent parce que sensible aux risques qui pourront se produire plus tard. Dans ce qu'a dit M. Meade il y a un conseil: s'occuper moins de croissance que de redistribution. Dans ce qu'a dit M. Tinbergen, ce qui paraît essentiel c'est son point de départ: l'importance de limiter la croissance des aliments; on peut discuter les chiffres qu'a présentés M. Tinbergen, mais il faut savoir si on veut partir aussi de ce point de vue original qu'il a justifié par la dégénérescence des plantes sélectionnées, des sols cultivés, etc.

Sans prendre parti sur la validité de chacun de ces points, un travail utile consisterait simplement à les écrire à la file, pour que dans deux jours nous puissions savoir si oui ou non nous sommes d'accord sur certains des principes qui figuraient sur la liste. Je ne crois pas que la conférence puisse apporter plus que cet accord sur quelques grands principes.

ABRAMOVITZ: I shall undertake, Dr. Coulomb, to talk with my colleagues here about the possibility of doing what you ask.

MUNDLAK: This is a response to the stimulating remarks by Shubik. It has to be responded to because in a meeting like this where it is mixed company the signals might be interpreted differently. So if one wants to point out that there is a dissatisfaction from the present state of theory, I will, as an empirical economist, for example, use an index and look at a number of articles that appear in theoretical journals and empirical journals which try to relate theory to reality. I have not conducted such a study but I would like to suggest that the rate of growth of such articles, at least the number of submitted articles, is higher than the rate of growth of population. So there is an intensive and increasing interest in testing and polishing the theory. The relevant question is not if we are satisfied but whether the present knowledge is useful or not. I think Professor Shubik—I do not know whether intentionally or not—has implicitly given the feeling or impression that somehow he has a framework whereby he can at least do better.

I think that the challenge that Professor Shubik should take (if he undertakes to grade society into groups —economists being one of them according to their usefulness) is to indicate on the subject matter of this conference where his recommendations would be different from the recommendations and analyses that were suggested by the panel of economists that we have had this morning. I think this is the point, because we are not here for the purpose of discussing economic theory; it is not a conference on economic theory and the ways for advancing it in the next generation. We have come up with some substantive methods and the question is, if this is not useful, then what else should be substituted for it?

MICHIELS: I want to make a very brief remark because I do not feel that Mr. Jantsch's comments on productivity and efficiency can go unchallenged. I do not see how one can justify using more human effort than is really necessary in order to produce a given good or service rather than releasing human effort for other activities. We should have enough imagination to think of other activities to do. I do not see how one can justify not using human effort as effectively as possible. This is what productivity and efficiency are about. I cannot see that as a criterion this can be abandoned. We may have to introduce constraints in order to prevent abusive use of this criterion and this can be done. But to abandon it as fundamental criterion for human activity is to go against the whole of history. All mankind has done through its past is to improve the efficiency and productivity with which it engages in any activity to enable it to engage in other activities.

BOL ALIMA: Sans vouloir faire des reproches aux organisateurs de cette Conférence qui se veut mondiale, je me dois cependant de faire remarquer que l'origine des participant et les sujets portés à l'ordre du jour tendent à ne refléter que les problèmes d'un certain monde, celui des riches et des forts. Cependant, puisque l'on est revenu à plusieurs reprises sur un problème qui me semble important, celui de la démographie, tendant à mettre en exergue que le sous-développement de nos Pays serait induit par le grand nombre de

bouches que nous avons à nourrir, je me permettrai une question. En effet, et ceci pour mon édification personnelle, j'aurais souhaité savoir si les éminents économistes qui ont eu à se pencher sur les différents problèmes que pose la science économique actuelle face au devenir de l'Humanité, ont eu à étudier, comme l'a dit le rapporteur, les leçons de l'Histoire en ce qui concerne les corrélations éventuelles entre le développement économique d'une part et les taux de croissance démographique ou les niveaux de populations d'autre part, si ces corrélations étaient étudiées, que ce soit dans les pays capitalistes ou dans les pays socialistes développés.

On serait alors en droit de connaître si le développement économique dans ces Pays développés a été induit par une réduction du taux de croissance de la population ou si c'est la population qui, en fournissant une main-d'oeuvre abondante a pu contribuer de façon décisive à ce décollage économique ou enfin si la baisse du taux de croissance démographique et le développement économique ne seraient que des phénomènes parallèles sans lien causal.

Je suis persuadé, Monsieur le Président, que c'est en répondant de façon nette à cette question que nous pouvons essayer de replacer objectivement le problème du contrôle des naissances dans un contexte réaliste humain, généreux et partant acceptable. Il est vrai que je ne représente pas mon Pays ici et que je parle à titre personnel. Mais si j'avais à représenter le Cameroun, je crois que j'aurais besoin de la réponse qui pourrait être donnée à cette question avant d'engager mon Pays à prendre position dans un débat si important pour le devenir de l'Humanité.

ABRAMOVITZ: I think I might begin to make an answer to the question which our friend has just posed so far as the past is concerned—particularly the past of the countries that are now developed. what we know about the relation between the economic development of western Europe and of the industrialized countries of European origin is that the early stages of development were accompanied first by a decline in death rates, as a result of which the rate of growth of population accelerated a great deal. That was followed at a later stage by a decline in fertility so that the gap between birth rate and death rate gradually narrowed and, as we know, at the present time over much of the industrialized portions of the world the net reproduction rate is again approaching unity. As to the question whether population growth merely accompanied economic development or was a help or a hindrance, that depends a great deal upon the relation between population and resources in the various countries. So far as the countries of new settlement were concerned, there is little question that the growth of population in those countries greatly speeded the growth of development and made possible the exploitation of the economics of scale which raised both the pace and the level of industrialization. At the same time the countries of western Europe, when they felt the impact of rapid growth of population, were able to avoid the possibly damaging consequences of too rapid growth of population because of the possibilities of emigration which existed during the nineteenth century, part of which was the more rapid growth of population in countries of new settlement. When we think of the situation today with respect to that part of the world which is poor, we again have to distinguish between those countries in which population pressure is relatively small and those countries in which it is already very great. My understanding, however, is that in connection with programs of economic development one central question is an increase in the amount of capital equipment which is available per worker. The capacity of the underdeveloped countries to accumulate capital is naturally limited—partly by their own poverty, partly by the limited flow of resources coming to them from the presently industrialized world. It is a very serious question, therefore, whether out of that limited flow of capital, gathered either from their own resources or from other parts of the world, a very considerable amount should have to be used, so to speak, to give increments to their population or whether it should be reserved for increasing the amount of capital per head. I might ask Mr Chenery, who has had a great deal of experience with the present problems of underdeveloped countries, if he would like to add to what I have just said.

CHENERY: I think you have covered the main points about what is known about the past. If we take recent growth rates there would not be very much relationship between population growth and per capita growth. Most of the notable examples of rapid growth are not the countries of highest growth, but there are some that are. So I think the correlation between G.N.P. growth rates and population growth, say in the last 10 or 15 years, is not high. It has much more to do with resources, investment rates, and other things.

TARZWELL: Several references have been made to biologists. As a biologist I would like to point out a few facts of life. All life on this planet is dependent on sunlight, air, water, and soil. We often hear, free as air and cheap as dirt. Under our present industrial development, pure clean air is no longer cheap and if you have tried to buy real estate recently, you know that neither is the soil. However, they are basic to all life, and the real basis of wealth is our natural resources. These countries that have depleted or do not have natural resources are really the poor countries. Those who have the natural resources are not poor, whether they are underdeveloped or not, because they are the ones who are going to accumulate the wealth in the future. I do not think they should feel too sorry for themselves if they have not squandered through exploitation their natural resources. We think of gold as the basis of wealth. It is the medium of exchange for natural resources. If the resources are not for sale or do not exist, what is its value? It is pretty, but we cannot eat it. If you were thirsty or hungry enough, you would give all the gold that you had for one glass of water and one meal. So the basic things are what you eat and drink. That brings me to another problem which I think has been left out here. That is water pollution. Our resources are renewable and nonrenewable. We are wasting

our nonrenewable, metallic resources, worldwide, by dumping thousands of tons out into the waterways and down into the ocean, where they are spread over thousands of square miles and cannot be recovered—at least not in time to do us any good in the future. I think we do not realize what we are doing. For instance in Delaware Bay silver is found in the sediments at 500 ppm. In Florida the effluent from a water desalinization plant contained 2000 ppm of copper. The effluent from a shell-loading plant contained several hundred ppm of copper. Oysters in the receiving water contained several hundred ppm of copper. They were green. These materials are toxicants. They are double pollutants in that we are wasting a nonrenewable resource, and we are polluting the waters which are necessary to produce another valuable resource, food. We have to utilize our forest, our grazing land, and our agriculture lands to the utmost, because food and shelter are essential. When we exceed the sustained yield of our forests, the carrying capacity of our grazing lands, and deplete our soils we are using them as a mining operation rather than cropping them, and we are in serious trouble because we are reducing their productive capacity. In Arizona the stockmen carried out a program for the control of the predators. If you are interested in wildlife or know about it, you know that when their predators were destroyed the deer increased. They did increase greatly in the Kiabab Forest. They ate the browse that was their regular food. Then they began eating the leaves and twigs of the trees, they ate up as far as they could reach when standing on their hindlegs. Before they died they ate the trees to form a definite browse line. So when you walked out there you saw all the trees browsed off to that line as far as you could see. What the deer did was to destroy the browse that was their basis of life. Without natural restraints on their population their numbers increased to the point where they destroyed their food supply. When the consumption of vegetation by animals exceeds annual productivity, base-carrying capacity is progressively reduced and, if continued, disaster strikes. There is a balance of nature which must be maintained. With the removal of the predators, the balance was destroyed. This can happen to any animal. Man has no predators, and he has largely controlled his parasites and diseases, so it is up to him to see that his population does not get so great that in the name of expedience he mines and destroys the resource base. If this occurs, starvation and fighting over what is left will reduce the population to a level which can be supported by the reduced carrying capacity. In the future, uses of energy—except perhaps atomic—are going to have to be based on the sustained yield of renewable resources. We may have to come back to the windmill, the wood burner, and the old hay-burner, in other words, the horse.

BRUS: I am an economist and I would not like to create an impression of returning recriminations. However, one of the aims of our presentation today was not only to help in a modest way the representatives of other disciplines present here, but also to get some necessary help from the distinguished audience of exact sciences in order to make the assumptions we usually make more precise and better founded. One of the most important problems from our point of view is the proper assessment of the degree of exhaustion of resources in the future. I am putting this to the representatives of geology and other sciences, not in order to press them for an answer now, because we are approaching already the end of our session, but in order to get an answer at all. What we got so far is very contradictory as far as the prospect of resource exhaustion (including technological progress) is concerned. Of course, in such a situation we will remain divided into optimists and pessimists because we can choose freely between very optimistic and very pessimistic statements made in this hall by the representatives of exact sciences.

One of the main suggestions made by our group is that we need now conditions for acting in a much more selective way than it was the case in the past. This is one of the paramount requirements of the present situation. We all like growth, but we like growth without pollution. So we have to find the means and ways to promote growth but to check pollution. Selective action makes, however, the business of resource allocation much more complicated. For example, Mr. Jaske, as an engineer, was probably right in complaining that the price of electricity and other kinds of energy is too low for accommodating (in economic sense) some technologically progressive methods of energy generation. May be from this point of view he is right, but he has to realize that the price system has many simultaneous functions. This what might be perfectly right from an allocative point of view might not be right from, let us say, a distributive point of view and the role of prices in distribution of income. If an increase in prices of electricity, I mean a much more significant increase than even the one witnessed at present, is advocated, this could have a very profound negative effect on the life of hundreds of millions of people in lower income brackets. This raises a problem, and I think rightly so, of the application of a dual system of prices which would be a more selective kind of instrument. From this point of view the suggestions made here from the panel with regard to the combination of some market and extra-market means of action indicate the need for institutions changes which would stand up to the necessity of applying much more complex solutions to the economic side of our questions. Of course, one has to be aware of the political, sociological, and other implications of such an approach.

ABRAMOVITZ: It is the chairman's role to be a moderator, and I would say to Mr. Brus that if he complains that our colleagues from other disciplines have not yet given us as much advice as we would like, he is invited, and we all are invited, to attend the plenary sessions that will take place this afternoon and on Thursday and Friday, and we shall lean a good deal more. Indeed, I think it would be best if I declared this meeting to have come to an end and at the same time point out that in preparation for this afternoon there will now at this time and in this room be shown a film which is presented by Mr. Higbie, the Chief of the

Division of Solid Waste at the U.S. Bureau of Mines, entitled "Wealth out of Waste." The film takes 27 minutes and Professor Marois feels that it is going to be a very useful preparation for this afternoon's meeting. We are all invited to stay and watch the film. In conclusion, I would like to thank all of the members of this group who attended today, not only those on the panel, but those in the audience who took part in the discussion. I think it was a very useful one. Thank you.

HIGBIE: The Bureau of Mines has recently released a new film entitled "Wealth out of Waste." It is on the subject of minerals processing, and includes the subject of recycling. It describes several waste disposal problems which we have in the United States, and shows how the Bureau of Mines, as a government organization, is attempting to solve these problems. It is, in our opinion, a good lead-in for this afternoon's plenary discussion, and I do appreciate your giving up a portion of the lunch period to view this film. I hope that you feel that it is worth your time.

Chapter IV

LONG RANGE MINERAL RESOURCES AND GROWTH

Président: H. Brown
Co-président: C. Guillemin

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REPORT OF THE GROUP ON LONG RANGE MINERAL RESOURCES AND GROWTH

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The working group began its discussions with the observation that the world is now divided into two major groups of nations. Some 930 million persons live in countries which can be called "rich" and some 2800 million persons live in countries which can be called "poor". Per capita, consumption levels in the rich countries are about 20 times greater than those in the poor ones. As a result, the rich human minority now consumes altogether nearly seven times the quantity of raw materials consumed by the poor majority.

The consumption of such commodities as steel and energy is increasing at about the same rate in the rich and poor countries. But the rate of population growth in the poor countries is some three times greater than in the rich countries and is increasing. As a result, the economic separation between the two groups of countries is widening. The proportion of raw materials consumed by the rich minority is increasing correspondingly.

The future demand for raw material depends upon the answers to three critical questions:

1. How affluent will the rich countries become?
2. To what level will populations of the poor countries grow?
3. How rapidly will the poor countries develop?

No matter whether our answers to these individual questions are optimistic or pessimistic in the absence of a major world catastrophe total demands for raw materials will grow in the years ahead to levels which are considerably higher than those of today.

Where will the needed raw materials come from? What proportion will come from recycling? What proportion will we continue to extract from nature?

Nature has concentrated the substances of which the earth is made in a variety of ways and in an infinite array of concentrations. The richest of these, which are usually not abundant, we call "ores". But our definition of an ore constantly changes with time. When ores of higher grade have been consumed, we process ores of lower grade. When these have been consumed, we move to ores of still lower grade. Of course, the necessary technology must be developed and the energy costs are increased. Usually, but not always, the monetary costs per unit of output are increased. Often the environmental costs will be high —or, as a corollary, if the environmental costs are to be kept low, the energy and monetary costs must be increased still further.

Another important factor to be kept in mind is that the development of mineral resources takes time. Exploration, assessment, and the development of new technologies can be major

rate-limiting factors in the availability of raw materials no matter how much money one is prepared to spend.

An especially important aspect of the availability of raw materials being used by man today is that for the most part they are not evenly distributed. The industrialized countries are using increasing quantities of raw materials removed both from their own lands and those of the developing countries. Most of these minerals are processed directly in the developed countries, greatly enhancing their value. This situation has already created numerous difficulties. The group foresees the possibility of even more difficulties in the years ahead as the developing countries increase prices of certain raw materials still further, as they reserve them for their own industrial purposes and as competition among the rich countries for resources increases in severity.

There was a consensus that the availability of mineral resources based on present trends could limit the future development of mankind. However, given adequate exploration, research, and development, sound conservation practices, recycling, and substantial capital investment, supply could reach the level necessary to provide an adequate level of living for the anticipated world population 50 years from now, provided it is stabilized.

It was also emphasized that the demands for freshwater are increasing rapidly because of increasing needs of agriculture and industry. The need for land is likewise growing, yet its availability is decreasing year after year because of the expansion of cities, industries, and highways.

As an important element of lessening the growth of demand, the group appeared to be in general agreement that manufactured goods should be designed in such a way that their lifetimes are increased, their contents of valuable raw materials are minimized, and so they can be recycled or otherwise utilized efficiently from the points of view of energetics and the environment.

There also seemed to be a consensus that growth rates in human society should be decreased, consistent with humanitarian objectives. Particularly critical are the growth of affluence in the rich countries and the growth of population in the poor ones. On the other hand, most of us agreed that the economic development of the poor countries should be accelerated with the objective of eliminating poverty and misery as quickly as possible. It was noted that this commendable objective would not greatly increase the worldwide demand for raw materials for several decades.

PROPOSITIONS D'ACTIONS

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Les instances gouvernementales et internationales doivent encourager moralement et matériellement les actions concourant à la mise en évidence de ressources nouvelles ou à l'extension de gîtes déjà reconnus. Pour cela devront être développées les recherches permettant d'améliorer les méthodes de prospection et d'évaluation des gisements, les technologies d'extraction et de valorisation des minerais et des matériaux.

Toutes ces actions devront être complétées par des études portant sur une exploitation plus intégrée, une utilisation plus rationnelle des matières premières minérales et sur une récupération accrue des déchets et rejets. Elles devront aussi tenir étroitement compte de la préservation de l'environnement et de la protection des autres richesses naturelles (eau, sol, air, paysages, etc.).

De plus, il est important de procéder à des analyses géoéconomiques intégrant les réserves et ressources des différents pays, leur développement économique et politique, les prospectives démographiques et les possibilités énergétiques qui leur sont propres. Cela permettra d'aboutir à des scénarios plurinationaux d'utilisation et de gestion rationnelle des ressources, préludes à des propositions de modèles mondiaux.

Le plan d'actions à entreprendre dans l'immédiat devrait donc comporter les points suivants:

1. un inventaire prévisionnel et prospectif semi-quantitatif dans chaque pays des réserves potentielles avec un indice de fiabilité qui sera fonction des connaissances géologiques locales;
2. le développement de la méthodologie de la prospection (en particulier recherches indirectes de gîtes cachés) et des techniques d'évaluation des gisements (modèles mathématiques) ainsi que l'amélioration de la technologie minière (exploitation et valorisation des minerais);
3. l'étude de système de disponibilité énergie-ressources étant donné que la demande énergétique est un facteur limitatif important de la croissance, l'estimation des coûts énergétiques en fonction des types de gisements, des modes d'exploitation, des conditions géographiques et économiques, devrait permettre de sélectionner les types et les systèmes d'exploitation les plus économiques en énergie;
4. l'accroissement des transferts scientifiques et écologiques des pays développés vers les pays en voie de développement, en particulier en créant ou en développant dans ces derniers des organismes d'Etat pour la recherche géologique et minière, la pédo-

logie et l'hydrologie de surface travaillant en étroite coopération avec des organismes internationaux;
5. l'étude de modèles géoéconomiques sur les matériaux ou métaux les plus typiques liant teneur et conditions d'exploitation et conduisant à des scénarios mondiaux de gestion des ressources.

Dans le domaine particulier de la récupération des déchets, le groupe pense qu'il faut intervenir par des mesures législatives et économiques mises en place par les gouvernements au niveau:

— de la production des déchets,
— de la réalisation du recyclage,
— du marché des produits recyclés.

Au niveau de la production des déchets, il est notamment nécessaire:
1. de faire l'inventaire des déchets par type d'activités, lieux de production et contenu, en tenant compte de leur variation dans le temps;
2. d'intervenir au niveau de la conception des produits de consommation de façon que soient produits ou fabriqués des biens de meilleure qualité plus durables et plus facilement recyclables;
3. de faire supporter les frais d'élimination des rejets à ceux qui les produisent et de les inciter à séparer le plus possible leurs déchets dès la source.

Au niveau de la réalisation du recyclage:
4. il faut que les décisions soient prises après des études complètes des avantages et inconvénients, en utilisant l'analyse des systèmes;
5. il faut agir sur les habitudes néfastes actuelles du goût de l'éphémère, au moyen de l'information et de l'éducation de l'ensemble de la société et pour cela utiliser au maximum les moyens audio-visuels actuellement tournés vers la consommation;
6. les gouvernements doivent faciliter la recherche technologique dans le domaine du recyclage, encourager les initiatives et démonstrations à l'échelle industrielle de nouveaux procédés par des subventions ou des allègements fiscaux;
7. il faut prendre les mesures économiques indispensables pour que des solutions avantageuses pour l'humanité deviennent rentables pour ceux qui les mettent en place (en particulier en internationalisant certains coûts ou avantages externes au moyen de taxes).

Au niveau du marché des produits recyclés:
8. il est nécessaire de normaliser et d'égaliser la situation entre matériaux naturels et matériaux récupérés, dans les spécifications des produits et les coûts de transport par exemple;
9. il faut régulariser à l'échelle nationale et mondiale les cours des déchets pour permettre des prévisions et des contrats d'une durée suffisamment élevée pour normaliser la profession de récupération et faciliter les investissements;
10. enfin, les gouvernements doivent montrer l'exemple en achetant davantage de produits recyclés et en les imposant dans les marchés d'Etat.

De telles mesures devraient permettre à la récupération de se développer et à l'humanité de profiter des avantages qu'elle apporte pour l'économie des ressources naturelles (ressources énergétiques et minérales) et la protection de l'environnement.

DISCUSSION

SHELDON: On the morning of the first day of our colloquium, the group discussed three aspects of resource availability and depletion. First, what is the potential of world mineral resources? And how well do we understand them? Second, what investments must be made by mankind to win them from the crust of the earth? And, third, what is the future prospect for the world mineral demand being met by primary supply?

Taking these up in order: the world mineral supply is directly derived from the *known* reserves of minerals, that is, those deposits identified and measured and economically profitable to mine. The reserve of most minerals will last only several decades, but this is no cause for alarm as mining companies usually only develop a reserve large enough to justify their investment, and they add to reserves only at about the rate that they mine.

A part of *potential* reserves are the mineralized rock from which the *known* reserves are discovered. They are a different thing entirely. They are undiscovered, unmeasured, and unevaluated. Estimates of their size must be predicted by geologists using their scientific tools. Such estimates have been made, albeit crudely and with very little data, and these preliminary results *are* cause for alarm. In general these potential reserves are about equal to the known reserves, or are larger only by a factor of 2 or 3. It should be realized, though, that these potential reserves are conservatively estimated, and this estimate can be expected to increase with scientific advance and collection of more data.

Also, it should be kept in mind that the other part of potential reserves include rock that is presently uneconomic to mine but can be mined in the future. So another way we can extend our primary supply is to learn how to economically extract minerals from those deposits that at the present time cannot be mined at a profit. This takes research and development in order to improve extractive and refining technology. The increased amount of minerals that this process will add has not been estimated at all. Its size depends on both the success of the R & D effort and the amount of subeconomic mineralized rock that exists as well as the price of minerals. Even though much of this R & D effort will be successful and even though much subeconomic mineralized rock exists, it seems likely that the increased mineral supply from this source is limited, at least for many minerals, for the following reasons.

It appears that the tonnage of some and perhaps most minerals does not increase as the grade of the ore decreases, as was thought in the past. In fact, the tonnage may decrease as was shown to be the case for the copper deposits of Chile, a major source of the world's copper. Thus, subeconomic resources may not be much larger than the economic resources, contrary to the assumptions of some modern economic models, and this may place a limit on the supply of some primary minerals.

How about improvements of technology? The exploitation of minerals is energy intensive. In fact, the availability of cheap energy was a major factor in the recent technologic advance. It has been shown that as the grade of deposits decreases and their depth and remoteness increase, energy costs go up exponentially. This, combined with escalating world energy prices also, may place a limit on the future primary mineral supply.

The second major subject of concern to the session was the investments required to bring resources into production.

It was felt that investments were needed to help the functioning of world mineral trade. The developed countries of the world are using their own minerals at an increasing rate as well as importing increasing amounts of minerals from the developing countries. Also, mineral processing, which greatly enhances the value of minerals, generally is done in the developed countries. This is causing severe strains in international trade and relations. The question of whether it is equitable for the rich countries to use most of the world's minerals at a cost of only the raw materials must be answered. Confrontation is to the advantage of neither side. Cooperation on an equitable basis is imperative. Thus an investment of statesmanship on the part of world leaders is vital. Improvements must be made in world financial institutions, international mineral treaties, international import and export regulations, and financial and development policies of both rich and poor countries if cooperative international mineral trade is to take the place of confrontation.

Investments are needed to appraise the potential of world mineral supply. The countries of the world need to kn[illegible] investments for

Investments are needed to increase the mineral production capacity of the nations of the world if their mineral potential is to be realized. Important investments in this area include:

1. The training of mineral scientists and engineers to meet the present world manpower shortages in these critical fields.

2. In the developing countries, investments in training managers of mining operations is especially needed to decrease the lag time between discovery of a mineral deposit and its production.

3. Finally, the investment capital required to increase the production capacity in all parts of the world is enormous. Where is this capital to come from? The mining companies of the rich nations are making low profits relative to other industries and are presently incapable of generating their own capital. In the poor countries, even government capital is insufficient. Despite the source of the capital, it must be found and invested if the world mineral production capacity is to increase.

The final topic discussed in our session was the prospect for world demand for minerals to be met in the future. It was generally concluded that at the present exponential increase of demand there is no chance it will be met. Exponential growth cannot last in a finite world.

This does not mean that growth of supply cannot occur, however. Man creates and drives his mineral supply system by (1) finding mineral deposits, (2) where they can be legally exploited, (3) with available mining and processing technology, (4) at a profit, and (5) with damage to the environment that is socially and biologically tolerable. There is little doubt that he will achieve additional success in this process, but at the same time these five necessary conditions to mineral supply impose potential limitations to their availability. Hence the five factors limiting the future primary mineral supply system are geologic, political, technologic, economic, and environmental.

The present status of knowledge of these factors makes an accurate prediction of future mineral supply impossible. Therefore, it is of first order importance to improve this knowledge. It is imperative that a substantial program of scientific, technologic, legal, political and economic research be addressed to these problems on a worldwide basis. It is imperative to construct a computerized model of the world mineral supply system to investigate the interaction of controlling factors.

In the absence of such a model, the following scenario, intuitively developed from existing trends, was suggested.

To meet demand for minerals, man would have to find increasing amounts of deposits which themselves become ever harder to find. Even with maximum science and technology, which seems unlikely to be achieved, this effort will fall short.

To meet demand, we would have to produce our minerals from increasingly leaner, deeper, and more remote deposits. Even with maximum technology, this effort will fall short.

Mineral prices will rise, and an increasing amount of society's efforts will go into supplying its minerals. The growth rate of mineral supply will level off or decrease, and in the long term be reversed so that supply itself will probably decrease.

This process probably will begin slowly so that the start will not be readily apparent, and the start will come earlier for some minerals than others.

Therefore, burgeoning demand of man for minerals will not be met, his desires to raise his level of living and extend it to all men will not be satisfied, and social, political, and economic institutions will have to adjust accordingly.

BROWN: Thank you very much, Dr. Sheldon. I would now like to open the floor for general discussion of this problem of resource availability and depletion. Feel free to ask questions or make comments of reasonable length.

PIORE: A year or two ago there was much discussion of being able to explore potentially from satellites for minerals. Is that just a dream, or what has happened?

SHELDON: Considerable research is going on in this area. The major impact is with the new earth satellite which is flown by N.A.S.A. with the data made available by N.A.S.A. and the U.S. Geological Survey to all the countries of the world who ask for it. There is no question but that this is a valuable tool—especially in unmapped areas. There is some very sophisticated research going on to see whether messaging by a computer, the data of which are digitized imagery in four wavelengths, will not help. Some promising results are turning up. However, it is only a tool and it can only see less than a millimetre into the surface of the Earth. As far as a panacea to greatly increase the mineral supply of the world, it just will not happen.

HORVAT: I am an economist and I am a little bit disappointed by the way that our colleagues have presented their forecasts. I have not seen any reason for their pessimism. It is true that some minerals are exhaustible. But it is also true that the total supply of minerals is inexhaustible for all practical purposes because it is millions of times the present consumption of them. Long before any particular mineral will be exhausted the price will go up and the supply and demand will be brought into equilibrium, by substitution,

and by saving devices of that particular mineral. I really do not see any reason why the present situation should be different from the past situation, since all the time we have been using poorer and poorer ores and all the time, on the average, prices of production have been going down, not going up. There have been exceptions for several minerals, but then the prices for other minerals have been lowered to such a great extent that on the average there was no increase but a decrease. I can see only two reasons for this pessimistic reasoning. One is unjustifiable identification of supply of particular minerals with the total supply of minerals. The other one is an unconscious assumption that the future generations will be much more stupid than the present generation and that the technological progress will dry out.

SHELDON: I should like to make one or two remarks on that. First, one issue that we were addressing is whether or not the supply will keep up with the demand that is being projected. That demand consists of estimating the amount required to at least hold affluence at its present level and spread it across the rest of the world to developing countries. I think our conclusion was that that sort of a goal was going to be very difficult to obtain. Second, if it is a matter of supply decreasing, raising prices, and thereby lowering demand, I do not argue with that at all, I think that will happen. But the real danger signals that we as geologists see are the supply of rock that is mineralized, and that it has a high enough grade to be remotely economic, is very limited. Also, the advances of technology are certainly going to be limited because the very basis of advancing technology has been cheap energy. As we go to lower grade, deeper and more remote mineral deposits, the energy costs go up exponentially. There has to be a limit to it.

GUILLEMIN: Je croyais que notre conférence concernait le long terme, pour ne pas dire le très long terme. Or, certaines des questions qui ont été évoquées, notamment dans le domaine monétaire n'ont évidemment une grande importance que dans un avenir relativement court. Aussi n'était-ce pas le sujet de mon intervention. Je suis tout à fait d'accord avec notre collègue Yougoslave pour penser que pour le très long terme, il ne peut y avoir de vues vraiment pessimistes sur l'avenir des ressources en matières premières minérales, ne serait-ce qu'en nous souvenant que nous vivons sur un tas de roches sphérique d'environ 12 000 km de diamètre. Néanmoins, comme je l'ai déjà souligné, il est clair que pour utiliser ces ressources il faudra faire appel à des quantités d'énergie toujours croissantes, et la seule vraie pénurie possible, c'est celle de l'énergie.

JOY: I will be very brief because Dr. Guillemin already said one of the things I wanted to say, and that is the limits of technology. This morning I have felt very flattered, being a member of the mineral processing expertise, at the confidence being shown in us in being able to continue to develop new methods which will be less energy consuming and just as cheap as the existing methods. I think that somebody should have pointed out that we are battling against nature and against the third law of thermodynamics and the amount of work which nature put into disseminating the ore. The ore is now very nearly, as Dr. Guillemin said, at the limits of our modern technology; this is coupled with the fact that the basic requirement of energy in order to extract the finely divided material just on a pure thermodynamic basis regardless whatever process you can invent, increases exponentially as the fineness and the dissemination of the ores increases. So there is a crisis point coming soon. Finally, your second point, sir, seems curious because it is begging the question. You said that the assumption was that the future generations are going to be as stupid. Well, surely, what we are doing right here and now is endeavoring to plan to ensure that the future generations will not be so stupid. The forecast we are giving is naturally therefore based on the assumption of what would happen if the future generations were as stupid.

HORVAT: Whether future generations will be more stupid or less stupid politically, I just do not know. They may just blow up the whole world. This is not what I was talking about. I only questioned the assumption that their intelligent quotient would be lower than ours. Because this assumption implies that if you take the present level of technology and then extrapolate the future means for resources because together with the future needs our resources and our technological knowledge will be growing. I question the assumption that this flow will dry out. If it will not, then we may extrapolate the present trend which has been not the increasing costs but the decreasing costs of minerals.

SCOTT: May I follow up the point that my neighbor, Horvat, has just made? I was struck by the remarks of Dr. Sheldon laying out the possibilities—very clearly but, if I may say so, in a way that was already familiar from our chairman's book, the *Challenge of Man's Future*, from the Paley Commission Report before that, and from the U.N.S.C.U.R.R. Report shortly after the Second World War; indeed, from the *Coal Question* by Jevons in the middle of the nineteenth century. The element which is new to me in what you gentlemen have been saying is the emphasis on the energy requirements for mineral exploitation. These were not—in those early reports—stressed to the same extent as you do today. I find that interesting. Now, if I may come to the support of Mr. Horvat (although he may want to reject my support). Mr. Harrison Brown said at the beginning that energy costs must rise. Your implication is, I think, that the energy costs of a ton of assorted metals have gone up in the last 100 or 200 years, and that, to extrapolate, they will continue to go up at the same rate. But neither Mr. Horvat nor I are sure that that is what you are claiming. You seem to be saying that with present technology, that is, with *today's* knowledge, to go to lower grade ore materials, you must use more energy. That must have been true 100 years ago, and indeed 1000 years ago. What we want to know is whether, with foreseeable *changes* in technology, you really expect that energy costs per ton of ore must rise. I think ours is quite a different question and I should be very glad if you could give us some help with it.

SHELDON: I should like to remark about the currency of the Paley Commission Report. For the rest of the audience that are not familiar with this report, it was a commission that was established by the American government in the fifties to make a study of the future of the mineral supply of the country. They had some very outstanding individuals on the Commission. For the most part it was an excellent report. However, it was flawed in one very critical sense; they dealt only with reserves and did not deal with potential reserves. They did not try to grapple with the very difficult problem of trying to estimate how much is left to be discovered. Two more modern studies have been made. One was a study by the U.S. Geological Survey that was published in 1973, called "The United States Mineral Resources". Another was a Presidential Commission on mineral recovery which was chaired by Dr. James Boyd, a past director of the U.S. Bureau of Mines. Both of these studies have approached the problem in a complete sense, dealing not only on the basis of the basis of reserves but also on the undiscovered resources. It is when you do that that all these other arguments begin to fall down. You begin to realize that you cannot simply keep going to lower and lower grade ores. In the first place, for the most part, they do not seem to exist. This excellent study by Dr. Carlos Ruiz, which was reported to our session on the copper ores of Chile, showed this in a very precise way. I do not want to answer the second part of your question. Other people are more able to do it than I. But I think that is an answer to the first part.

GAUTSCH: Je souhaiterais que nous nous arrêtions un instant sur le problème des investissements et des capacités de production à long terme. A la différence de notre distingué collègue, qui est intervenu tout à l'heure, je suis non point économiste, mais géologue minier, et c'est aux économistes que je vais lancer un appel. Peut être la conférence n'a-t-elle pas mis suffisamment l'accent sur les rapports qui existent entre le devenir des matières premières minérales et la remise en ordre du système monétaire international. Ainsi que j'ai eu l'occasion de le dire dans mon intervention, les pays en voie de développement, tout en cherchant très légitimement à transférer chez eux la technologie appliquée à la transformation des matières premières auront besoin pendant un temps encore assez long de disposer de moyens d'échange et de paiement, ne serait-ce, précisément, que pour asseoir les moyens de leur développement industriel. Or, dans les circonstances présentes, ces pays ont le sentiment qu'ils vont échanger leurs matières premières, c'est-à-dire en fait leur potentiel d'avenir, contre des créances-papier, fussent-elles libellées en dollars ou en francs suisses. Cela est déjà vrai pour certains pays pétroliers, cela risque d'être vrai demain pour certains pays exportateurs de phosphate (et vous connaissez l'importance de cette matière première pour le développement mondial de l'agriculture), cela sera peut-être vrai après-demain pour certains producteurs de métaux, tel l'étain, dont vous savez aussi que les réserves mondiales sont relativement limitées. Alors la question que je pose est la suivante: cette situation n'aura-t-elle pas une incidence directe sur l'exploitation à venir des ressources naturelles, car il se produira dans les pays détenteurs de ces ressources un réflexe de frein aux investissements de recherche et de mise en valeur? Etant donné les difficultés qui existent par ailleurs de prévoir des limitations pouvant s'exercer sur la consommation, les économistes et les financiers rendraient un service signalé à l'humanité, s'ils trouvaient les moyens de supprimer cette entrave aux investissements pour l'avenir.

LEHMAN: Je suis tout à fait d'accord avec notre collègue Yougoslave pour penser qu'à très long terme, il ne peut pas y avoir de vues vraiment pessimistes sur les ressources minérales dont nous pourrions avoir besoin, ne serait-ce qu'en nous rappelant que nous vivons sur un tas de cailloux sphérique d'environ 12 000 km de diamètre. Néanmoins, comme il a été dit, il est clair que pour disposer des produits minéraux soit actuels, soit non-employés actuellement, dont nous aurons besoin dans le futur, il faudra faire appel davantage à une consommation d'énergie accrue, et la seule pénurie possible est évidemment celle d'énergie; c'est par exemple le cas de l'aluminium, dont l'emploi n'existait pas il y a cent ans, et l'aluminium est le produit de cailloux sans valeur il y a cent ans et d'énergie. Aussi ma question est la suivante: demain matin se tiendra le panel sur les Ressources Energétiques à Long Terme: nos collègues géologues et minéralogistes qui discutent aujourd'hui ont-ils remis à nos collègues sur l'énergie qui discuteront demain matin leur plan à long terme sur la part de l'accroissement des besoins énergétiques du globe qu'il sera nécessaire d'ajouter aux prévisions faites sur la base des besoins consacrés aux consommations actuelles d'énergie? Autrement dit, avez-vous commencé, Messieurs les géologues, à prévoir de combien d'énergie supplémentaire vous aurez besoin pour exploiter des minéraux qu'on n'exploite pas aujourd'hui, et puis-je émettre le voeu que vous remettiez de telles prévisions avant la réunion de demain matin, qui en aurait certainement un besoin capital.

GUILLEMIN: Je vais me permettre de vous répondre. Je vous dirai simplement que nous ne risquons certainement pas de remettre de tels renseignements à nos collègues du panel sur l'énergie, pour une raison simple; c'est que nous avons commencé à nous occuper du coût énergétique de transformation des minerais en métaux depuis extrêmement peu de temps, c'est-à-dire depuis la crise de l'énergie. N'oublions pas que le Comité Energie du 6ème Plan n'envisageait pas dans son rapport final, la possibilité d'une augmentation substantielle du prix du pétrole. Nous ne sommes certes pas plus intelligents que les énergéticiens et c'est seulement maintenant que nous commençons à nous préoccuper du coût énergétique des minerais.

SHELDON: I should like to add to those remarks by Dr. Guillemin. It certainly is the case that the energy requirements are going to go up for mineral production per unit of metal. That is the energy cost in terms of Btus. Whether the energy costs in actual financial cost goes up depends on the cost of energy. If we get a successful fusion reactor and there really is extremely cheap energy, the point can be raised in that event. Is

there going to be a shortage of minerals? In this case of extremely cheap energy there are still some fundamental factors which limit the mineral supply. One of these is the damage to the environment. Another resource that is absolutely essential for technology and for the processing of minerals is water. This is a resource in the shortage category. There is a finite limit in the amount of water. One last point I should like to make is that no amount of research by engineers or scientists on the technology of mineral processing or mining can overcome the basic amount of work required to mine rock. And to break the chemical bonds between let's say lead and the sulfide in the mineral galena or any other mineral that you want. So technology does not overcome the laws of nature. This is a point that Dr. Joy was making and I endorse it.

BROWN: Thank you. I would just like to add to that. Many of us probably feel that it was probably not right to separate the minerals' availability discussions from the energy discussions. You really cannot divorce the two. In a sense, what is a resource depends markedly upon the availability of energy.

AUGER: The report mentioned quite rightly the question of waste, production of waste material, and recycling of waste materials. One of the tendencies which I believe to be a dangerous one, and is increasing, is the tendency to produce and put on the market throw-away objects. We have started by throwing away bottles and then ballpoint pens, producing shirts which cannot be washed or socks which cannot be mended and have to be thrown away. We are now throwing away our cars. We are throwing away everything without even trying to repair it or use it for a longer time. The report mentioned some possibilities against this tendency: legal ones of course. One could prohibit the production of flash lamps which cannot be fitted with new batteries and have to be thrown away. One could stop this kind of production, or could try to make fashionable the repairing of instruments or the use of recyclable materials. I know that in California, for example, it is now fashionable among the young ones to use glass bottles which can be put once again in the circuit and *not* to use plastic materials which have to be thrown away. A fashion like that could probably be encouraged. I wonder if the report is sufficiently strong on that point.

BROWN: Might I say, Mr. Auger, that the greater part of our discussion here will deal with the problems of recycling. So this will be discussed.

BLACKSHEAR: I should like to come back to the problem of going to lower grade ores, recycling, and the costs involved. Awhile back, Alvin Weinberg and his associates made an estimate of these costs. He included the mining of lower grade ores that were in abundance (iron, aluminum, and magnesium) and estimated the energy cost for a world population of 15×10^9 and a level of development of U.S. in 1970, i.e., 10 kW per person for recycling scarce metals, 2 additional kW per cap per person would be required over present energy costs, whereas for iron and aluminum the added cost is 0.1 kW; water by desalination would require 0.3 kW, and so on. The intensive use of low-grade ores and the attendant need to manage waste and to purify water amounted to 6 kW extra *per capita*, I wonder if your group had considered Weinberg's study and had rejected it for some reasons you have not told us?

HAYES: If you will just wait for the next one or two reports, I think this will all come out.

LEWIS: I think the best affiliation is atomic energy. We have been referred back to Gibbons and to the Paley Commission Report. But there is a lot more literature besides that, I am surprised that no one has referred to the 556-page book, *Energy in the Future*, by Palmer Putnam, who in 1950 foresaw that in 1975 the price of oil would probably have risen because of the demand to the state that the synthetic hydrocarbons would be coming in. None of these forecast books is ever right throughout, but there is a lot to be had from them. The problem that you are tackling at the moment with Dr. Horvat is a very old one—the argument between the geochemist and the mining engineer. The mining engineer does not find very much that is cheaply available; the geochemist tells him there is a lot there. The thing I really rose to speak about was this statement that as you go to work lower grades ores the price goes up exponentially. This does not mean a thing. It is a question of how long. Nuclear energy will be available, very cheaply, if you do not ask for it tomorrow. It is a question of time. The active effort is required to build up the capital, to have it, but when it is there it is very cheap. At the present time the performance is that we get as much energy out of a ton of natural uranium as out of 28 000 tons of the best coal. That is the present practice. We can see going over to thorium instead of uranium and this figure going up well over 100 000 tons of coal, that much energy for a ton weight of uranium or thorium in the fuel. This will be at a very low cost in terms of man hour effort to produce it. But you have to wait to take this exponential rise far enough for this to be significant. We are not on that significant level yet but certainly within the next 50 years, really within the next 30 years, we will be on a significant level there. So what we want to know is how rapidly the energy demand will rise on your predictions—because I assume that you are really looking at this question of the ore quality in a number of significant mineral resources—how rapidly will it rise in relation to the demand?

SHELDON: I certainly agree that that is a very important question to answer. That is one of our recommendations that such a study be made. I should like to observe also that in the case of obtaining energy from uranium, it is only if you have the fusion reactor that prices can be so low that you can stop worrying about these exponential costs, because the resources of uranium are much more limited than anyone ever thought—you shake your head, but they certainly are.

LEWIS: The suggestion that the uranium resources are lower now than anyone ever thought—I find this preposterous.

term, that man has no alternative but to develop recycling to the highest point possible. Solid waste collected annually in the United States—I am not going to bore you with many figures, so do not go back to sleep—includes 30 million tons of paper and paper products, 4 million tons of plastics, 100 million tires, 30 billion bottles (that's a lot of beer), 60 billion cans, million of tons of demolition debris, grass, and tree trimmings, food waste, and millions of discarded major appliances. Of our waste materials, on a percentage basis, organic refuse, including paper and plastics, make up about 70% ceramics and glass about 10%. Metals—mostly iron—make up about 10%. It is down in this metallic fraction, the smallest volume, where we have the greatest resale value of material possible. But it is in the organic or in any energy fractions that have the lowest value and the largest bulk. It has been remarked—in a study by Brevard in Oak Ridge, that recycling aluminum requires only 5% of the original energy of reduction. In the case of iron it takes about 25% of the original iron energy reduction to recycle iron. You go on up to the exotic metals like titanium and zirconium and it goes much higher, of course. This is all covered in the Oak Ridge study referred to. It has been estimated that we could achieve a 2% energy saving in the United States simply by recycling the solid materials out of our waste material. There is a second type of energy saving besides that just in the metal bit. That is the use of the organic fractions as fuel. The paper, plastics, and garbage can be used as fuel and incinerated. They can also be transported into transportable, storable fuels. It has been calculated that the United States might meet 5% of its energy requirements by following this scheme. Of course, the problem of collecting all the urban refuse and of utilizing them fully are a long way from realization. The third point is a virgin resource saving of materials, of a materials orientation. The obvious truism is that for every ton of material saved we do not have to go and mine a ton of material out of the ground. This brings into play a fourth benefit—capital savings. As I have said, the capital required to produce material from recycled product or scrap is considerably less by several factors. Heaven knows we need any capital savings methods that we can promote today. It is also a savings of pollution and control investment. This has become a formidable part: 20% of the cost of a blast furnace is in the pollution and control equipment. This is a non-productive investment. I am not going to argue about the environmental part; I am saying that it is non-productive. And look at the tons of steel you get per investment in constant dollars and see how much it has gone down in the last few years and will continue to do so. I might point out that Reynolds Metals, which is one of the leaders of aluminum recycling in the United States (they are all in it now), has estimated that their program of collecting cans, aluminum cans at collection points, is the equivalent of another 25 000 ton potline. So this is a lot of energy and capital savings. Recycling of municipal wastes necessarily implies certain resource degradation. Systems designed today can separate iron from aluminum and aluminum from glass and glass from paper, but they do not do well in breaking down the subgroups of the aluminum alloys or different plastics. They cannot economically sort glass by color and they cannot sufficiently eliminate all of the grease and dirt, all of the contaminants of paper. So thus there is a resource degradation. While this degradation of materials is a limitation on recycling it does not have to be serious one. The virgin resource industry can capitalize on recycling to restrict the use of virgin ores for their highest and best use. One of our speakers addressed the point of plastics and energy and waste handling. Plastics contain about 19 000 Btu a pound—about the same amount of energy as oil. So the implication is that crude oil and natural gas can first be directed into plastics and petrochemicals; its market value is many times the market value of petroleum products as energy. Petroleum products have to be made into petrochemicals and plastics and then can be recycled on the waste cycle into energy through incineration, pyrolysis, or hydrogenation. Some petroleum products cannot be recycled. These include fertilizer products which have raised corn yield per acre by two-thirds and permitted the world to feed a larger economy. Obviously feeding people is more valuable than driving a second or third automobile. Let me digress at this point. It is not understood too well that ammonia is a widely used fertilizer, but the amount of energy to produce ammonia is somewhere between steel and aluminum. It is much more energy intensive than paper, copper, and steel. This is the reason ammonia goes from $60 to $120 to $250 a ton in about two years. It is the bidding for the energy short materials. We are not short of materials; we are short of available energy. I remarked, of course, that virgin aluminum can be recycled. The recycled makes good can stock and good castings. Similarly, a lot of iron is recycled to make lower-grade roll mill products and angle bar for which it would be foolish to use first-grade materials when you can get by with the lower-grade material for the particular use and reserve your virgin ores for higher specification uses.

This, while it may be the least specific in terms of numbers, is probably the most valuable concept that comes out of recycling: the use of virgin resources to produce the highest valued products in the market place and in society necessarily allocates the highest amount of energy to the most valuable areas of consumption. Thus if there is one theme which runs through the recycling field in materials, fuel, capital investment, and reallocation of resources, it is our ability to decrease our dependency on a commodity called energy which is no longer cheap and our ability to conserve that commodity while conserving on other ores as well. This may be our best assurance against the dire predictions that this is a technological level and socioeconomic level which will be unique in the history of the world and generally unsustainable. Recycling is not the total solution to these problems, but it can make a major contribution in the reorientation of the resource economy toward these goals.

BROWN: Thank you very much. I open the floor for discussion.

HERBERT: I should like to give a few numbers relative to the energy savings from a total recycling plant. We have done an energy balance and I have some numbers I think some of the audience and colleagues here would appreciate hearing. This is the net energy available or the net savings in energy after you have spent the energy within the plant itself. If you go all the way to electricity, you can generate about 430 net kWh per ton of waste that is processed. From the iron that you recover from the plant you will save 616 800 Btu per U.S. ton or 814 180 kcal per metric ton. On glass, you save 91 200 Btu or 120 000 kcal. On aluminum and other nonferrous materials, you will save 13 870 000 Btu or 18 300 000 kcal. Converting those energy units or the calorific units into electrical energy the net savings is 610 kWh per ton of waste processed. This does not, however, include the energy that was required to make the raw materials that are consumed in the manufacture of, say, iron and aluminum. In other words the energy to make the caustic soda and the soda ash is not included on the savings on the glass.

YAROSH: Much of the discussion which occurred applies to the discussion on recycling and has to do with a concept that is gaining a lot of attention. That is the calculation of net energy costs both in goods and services and in all our activities. Although this was touched upon, it was not explicitly stated. It applies not only to the net energy costs or net energy yields of our activities—for example, the energy costs of mining for energy sources, the energy costs of producing even the equipment that goes into the mining processes, and the energy costs of recycling. For example, in the recycling of glass, I think the people at the University of Illinois Center for Advanced Computation indicated that the recycling of glass—that is returning to the factories—is a much more energy-intensive process than the manufacture of returnable bottles. So the direction to go, for example, may not be recycling glass but rather the manufacture of returnable bottles. This whole concept of net energy yield I think is an enormously important one that we have to expand to all of our mineral activities, all our activities in mining, and in the many different things you have mentioned. I have seen early calculations that are looking at the net energy yield of our nuclear industry, the energy costs in extracting, in obtaining the energy yield from the nuclear industry. I should like to suggest this as an important concept that we ought to examine in great detail in attempting to understand more clearly what the costs are of our activities, and perhaps an energy basis might be a very useful one for determining the directions we ought to go.

HAYES: This is the name of the game around the world today. Part of our problems, of course, are the acuteness with which this energy shortage developed. Some people called attention to it 20 years ago, but really it is only in the last five when the cost of energy changes, as in the case of American coal, from 50 cents a million Btu to $1.50 a million Btu in 18 months; this shakes the very heart of industry. When you consider that the United States will have half of the natural gas in 1990 available that it has today, then rapid action is called for.

HERBERT: With respect to the last comment about recycling glass, taking more energy than virgin glass, I think he is referring to a report by Dr. Bruce Hanlin, and in there you will find that he quotes as an authority on it one William Herbert, which is me.

BROWN: I am sorry, he did not make that statement. He was talking about a returnable bottle.

HERBERT: That is correct. He quoted me out of context and I disagreed with him violently and so did Ownes Illinois, the glass company, and he refused to change it. Do not believe what he told you in that report, sir.

RHYS: Firstly, I would like to comment on the conclusions reached that recycling is not always the answer. Quite obviously I agree with those conclusions. Recycling should really only be considered for certain well-defined situations. I use recycling in its widest term, of course, to include energy recovery. Obviously we should focus our attention on affluent areas, usually densely populated, producing and demanding consumer goods, and producing and demanding packaged goods. Packaging is often wasteful according to the standards the advertising media have conditioned them to expect. That is one thing we might just focus our attention on a little—the education of the public. It seems to me that if we concentrate our efforts, our recycling efforts, on such target areas, properly developed recycling will in fact almost always provide a significant contribution, if not in absolute terms "the answer." That is one point. Another point is that we have had a brief opportunity of considering recycling methods as they are today. Dr. Joy did the very best he could to bring to the attention of the people present one or two methods. Most of us here I think realize that recycling in fairly original form of inorganics is perfectly feasible and the economics may be marginal or they may be in fact quite good. I really want to say that such ideas are certainly not conceptual. The United States B.M. film probably emphasized that. They are way beyond the experimental stage. Some in fact are starting to go on stream, though possibly at fairly low rates at the moment. The third point that I do not appear to have heard is anyone referring to recycling as a business opportunity. I recognize that this conference has to have somewhat elevated ideals; nevertheless, we do live in a sordid commercial society and to quote the Americans, amongst whom I now live, "If it don't make a buck, it just ain't gonna fly." A last point, made with deference, takes issue with Earl Hayes and his comments on the economics of color-sorting glass. If in fact he checks up-to-date information and the state of the art considerations, I think that he will find that very often color sorting can be economic, and I would like to discuss it with him over a beverage from a recyclable color-sortable container.

HAYES: Well, in the first place I'm color blind, so he might beat me in that examination. Let us say it is like horse racing, there is a difference of opinion that forms the industry. I did not discuss the economics of this, but recycling is a matter of economics and some of you heard me talk. In the old days we had the man who picked up old rags and paper and brass and iron. In the modern day we have much more sophisticated techniques. Recycling really was not going too far as far as urban waste is concerned until the last few years when land became more expensive and sanitary land fills made the cost of burial much higher. Environmental considerations have pushed up the cost, and this unspecified cost is very, very real. In the last year all the economic considerations we have had of energy in our lifetime have been shaken to the very core. All these push recycling along at a pace that was simply not envisaged five years ago. In the last analysis it has to go in the marketplace. All sorts of nice considerations will not make it work. But environmental laws, high cost of energy, high cost of land—these will make it go. Does that answer you?

ZRAKET: I want to make some brief contextual comments on the use of energy in extraction, recycling, and processing of materials. I do not think there is any disagreement that we need to look carefully at the efficiency of the net energy costs on these kinds of needs. However, I think we are losing sight of the larger question that was raised with respect to the use of technology in extending the use of resources. After all, it is the end-use system or systems which we have in the economy which are of interest. Even though it might cost us—although I would not agree with this hypothesis—twice as much energy in Btu to extract resources, the fact of the matter is that we can gain factors of thousands in efficiency in the end-use systems. It might cost us today twice as much to extract the materials needed for computers but, considering the net energy used, computers are a thousand times as efficient today as they were 20 years ago. Similarly, this can happen in our industrial systems, transportation systems, in our building systems, in our lighting systems and so forth. So in looking at what technology can do with respect to extending the life of resources, it seems to me that we must take a look at the total system in which technology can make a contribution. In this case I feel very positive, as some of the previous speakers felt. I feel that we need much more rigorous economic and technical analyses of this situation rather than moralistic statements on how wasteful we are. To deny the insufficiently developed countries the benefits of a mass consumption society on the basis that we have a set of finite resources which we are going to start running out of in 30 or 40 years, is a statement that needs much more economic and technological analysis than just saying we are being wasteful.

CALLAHAN: As we meet to discuss water as part of a plan of action for mankind in a world of technological change, increasing population, and water demand, let us keep in mind that the world water supply has essentially neither increased nor decreased since the earth atmosphere was formed millions of years ago. While water use continues to escalate in response to an expanding world population, which is expected to double in the next 35 years, the total amount of available water remains the same.

The uneven distribution of water resources has long been a problem. Droughts experienced in this and recent decades have prompted increases in water recycling and brought about a more general awareness of the benefits of reuse. Some major cities in the world already withdraw river water that may contain as much as 50% sewage affluent. Numerous reports attest to successful spray irrigation of sewage effluents that stimulate crop production, and land spreading techniques have been used successfully to dispose of wastes and, at the same time, to reclaim or upgrade poor and despoiled areas.

Artificial recharge of aquifer systems for water-supply storage and as buffers against salt-water intrusion is becoming more common. Thus, it would seem that there is no longer the question of whether water should be recycled, but rather how, where, and when it should be done.

During these meetings we have heard of impending shortages of energy and minerals that may tend to limit the advancement or development of mankind. Of all of these shortages, none will be more important or more limiting than water. And, basically, we are limited economically to the freshwater that falls on the continents and returns overland and underground to the seas.

For the United States we can project water shortages in half of the country by the year 2000 based on present usage and technology. Changes in usage and improvement in technology might lessen the projected shortages, but with population increases there still will be shortages and probably a deteriorating quality of life.

The deteriorating quality of life that the world faces is caused by far more than population pressure. It is caused also by increased *per capita* demand, faulty technology, and mismanagement. With respect to water resources, one of the most common results of mismanagement has been contamination. Water, whether in a river or underground, is susceptible to contamination from both man and nature. As populations increase, the susceptibility for contamination increases. As land becomes more densely populated it becomes increasingly difficult to prevent contamination. Exclusive of man, the protection of water is dependent on the interrelated factors of climate, vegetation, soil development, and geologic and topographic conditions.

It is man's activities, primarily, with which we are concerned here. How do water and agriculture fit into a world of development and recycling? Will people accept reclaimed water, and, if so, with what limitations?

Water will be in greater demand. More will be required for irrigation agriculture, and consumptive use will increase. Return flows to rivers or to underground reservoirs will carry increased loads of fertilizers, insecticides, and herbicides.

In the 17 semi-arid western States of the United States, water withdrawn already is 90% of the dependable supply. About 20% of that withdrawn is lost to consumptive use. Water use is increasing about 3% per year. With the advent of oil shale development and surface mining and the water uses attendant to production and land reclamation, consumptive use is scheduled to increase dramatically. As a possible trade-off in water use, agriculture may have to return from the semi-arid west to the humid southeastern United States in order to lessen the impact of consumptive use and increased salinity of western rivers.

In our session on water and agriculture we have heard of the experiences gained through studies and experiments. In Pennsylvania, U.S.A., animal wastes have been recycled on to the land to produce animal feed and trees. The farmed study area is in a temperate climate where annual precipitation is about 1000 mm, and they have successfully sprayed more than an additional 1000 mm of liquid wastes. Feed crops and trees have removed essentially all the nutrients, and the soil aided in the removal of bacteria and viruses. A monitoring system indicates that the water leaving the farmsite is of a good quality, including chemical, biological, and aesthetical characteristics, as the water in nearby streams. In other words, by recycling the wastes the entire environmental setting has been enhanced, and fiscal profit has been earned by a savings in fertilizers used, and feed crops and trees produced.

The recycling of municipal wastes can and will be beneficial not only to the world of agriculture where much can be used, but to the cities which will be aided in solving their problems of disposal, and to the downstream users of the streams who will not have to suffer the problems of heavily polluted rivers.

We heard the results of several years' experiments on the recycling of municipal sewage sludge in the outskirts of Washington, D.C. by the U.S. Department of Agriculture's Research Service. Questions that they are trying to answer include: whether the methods are economically and technically feasible; will the methods be politically and socially acceptable; what are the benefits and the hazards to soils and crops, animals and man?

In a completely different environment, investigations of the hydrologic aspects of recycling water are being made in permeable carbonate rock of relatively warm and humid Florida, U.S.A. The region experiences an annual cycle of drought and water surplus. With the increased demand for water for agriculture, industry, and public supply, each succeeding drought causes economic hardship, and it is estimated that in the next 10 years Florida may be the greatest user of recycled water. The recycling methods so far used include spray irrigation of waste water on green belts and golf courses, storage of storm runoff underground in permeable saline aquifers, injection of effluents from secondary or modified advanced waste treatment plants into deep saline water aquifers, and the use of digested sludge in the production of grass sods.

A U.S. food processor has deliberately located food processing plants in rural areas where they have utilized the local environment to treat the waste waters of the processing plants. In one system, water is sprayed on sandy soil, where the quality is improved by filtration and plant production, and at another by utilization of an overland-flow system, where the soil is too impervious to permit high infiltration rates. Both systems have been successful in removing more than 98% of the B.O.D. for a period of several years.

Studies have been made of a region where more than 2.5 million persons depend entirely on ground water for supply and where, until recent years, the water was almost completely recycled through septic tanks and sewage treatment plants back to the underground. This resulted in deterioration of ground-water quality, with a significant increase in nitrate and other dissolved solids. Because of the limited supply of water, waste-water reclamation and ground-water recharge experiments have been conducted to determine the technical limits. However, the data indicate that in the recycling of water, the increase of total dissolved solids is inevitable.

The city of Chicago, situated on the shores of the Great Lakes, has the problem of disposing of an ever-increasing volume of municipal wastes of several million persons. They have been recycling digested sewage sludge on farmlands and abandoned strip coal mines with good results. Data indicate that, among other advantages to the methods, viruses are not likely to survive the heated anaerobic digestor environment and be transferred to the disposal site. The studies also indicate that the land has a limited capacity to accept digested sludge, and that if the limitations are exceeded some of the more soluble heavy metal constituents may adversely affect the growth of crops or result in the accumulation of some chemical elements in crop tissue at concentration levels that might pose a threat to animal or human health. The use of sludge on abandoned strip mines has improved the agronomic properties of the soil and helped neutralize the acidity of the overland runoff from the mines.

A study of a heavily industrialized valley in Korea has shown that the infiltration of industrial wastes to the sands and gravels underlying the valley has permanently altered the chemical quality of the streamflow that drains the area. The low flow of the stream, derived from ground water, has a pH and dissolved solids significantly altered from that of nearby streams draining agricultural valleys.

The data being accumulated in present and recent studies indicate that the recycling of wastes and waste waters is technically and economically feasible within limitations. We are also re-learning what past civilizations have learned; that wastes can be recycled.

The public must be educated to accept the concept of using reclaimed water and other reclaimed materials. A study of public attitudes [Brovold, William H., and Ongerth, Henry J., Public use and evaluation of reclaimed water, *Journ. AWWA*. 1972] made in California indicated that more than 50% of the respondents

to the survey recommended against using reclaimed water for purposes involving personal contact. The study also showed that most persons favored treatment and reuse of waste waters but for purposes not involving significant personal contact.

In conclusion, we have the following suggestions for your consideration:

In developed countries, for planning and conservation

The increasing rate of the total *per capita* water usage in developed countries is beginning to pose a serious threat to this limited resource. Developed countries should implement conservation of this resource by more effective management and utilization of water for agriculture, industry, and reaction, because the direct consumptive needs of man are minimal and fixed.

In developing countries, for planning and conservation

Developing countries should incorporate in all their long term planning a sound program of water management and conservation to insure against diminishing or diminished supplies that would result from overuse, improper development, or contamination.

Effects of recycling

The session on effects of recycling upon water and agriculture indicated that:

1. Recycling, properly controlled, can aid in:
   (a) reducing the impact of wastes and waste disposal on the hydrologic environment;
   (b) having a positive benefit on agriculture and potential benefits to industrial and other uses;
   (c) improving effective use of water resources through improved water management.
2. Recycling, where technically feasible, may be implemented by various methods, among which are:
   (a) land spreading of treated effluent, sludge, and animal wastes;
   (b) subsurface storage of effluents and storm runoff for treatment and reuse.
3. Prior to implementation of recycling:
   (a) methods to be employed must be carefully assessed;
   (b) assessment must encompass broad aspects and details of the hydrologic setting;
   (c) consideration must be given to use of simulation and predictive techniques based on the current status of computer technology for modelling flow systems and chemical and biochemical reactions.
4. Once implemented:
   (a) recycling must be adequately monitored and data continually evaluated in order to protect water resources;
   (b) care must be exercized in all types of recycling to insure that contamination of water resources and the biologically active soil zone is kept to a minimum.
5. Recycling, even under the most favorable conditions, can result in some degradation of the hydrologic environment.
6. Emphasis needs to be continued upon improving the ability to quantitatively simulate and predict the impact of recycling.
7. In general, adequate technology exists to permit improved management and use of water resources through controlled recycling without unduly harming the hydrologic environment.

BROWN: Thank you very much. Because of the close relationship between this presentation and the following one I will defer discussion until after the next presentation. I would like now to call on Mr. G. Aubert who will discuss the effects of recycling upon agriculture.

AUBERT: Le titre de la discussion que nous devions avoir est bien, en effet: "Effets du recyclage sur l'agriculture". Et quoique, comme l'a fait remarquer dans la discussion le Professeur Keiling, notre conférence mondiale "Vers un Plan d'Actions pour l'Humanité" aurait dû comporter un colloque tout entier sur les problèmes des ressources biologiques et de l'agriculture en particulier, dans le peu de temps que nous avions à notre disposition il ne nous a été possible de traiter que d'un seul sujet, d'un seul élément, le sol. Le sol, qui est une ressource organo-minérale naturelle, plus ou moins modifiée et transformée par l'homme. Le rôle du sol est essentiel, d'abord parce que c'est lui qui porte la végétation, végétation naturelle ou culture, génératrice d'aliments, de biens extrêmement divers, végétation qui permet le maintien de certaines qualités, de certaines caractéristiques du climat, de l'atmosphère, végétation qui concourt à garder à la surface du sol, à la surface de la terre, des lieux de repos, de détente et de loisir qui apparaissent de plus en plus nécessaires. Et puis, pourquoi le cacher, le sol par l'intermédiaire de la végétation est bien l'un des éléments essentiels qui nous permet d'utiliser une énergie inépuisable: l'énergie solaire. Mais à côté de ces rôles du sol dans la vie de l'humanité, il en est d'autres qu'il ne faut pas mésestimer non plus, surtout quand on touche au problème du recyclage, c'est le sol comme support d'éléments à recycler. Il est donc indispensable de maintenir le sol, d'éviter sa destruction et, chaque fois qu'il est possible et que le sol a été complètement remanié, retransformé par l'action de l'homme, essayer de le recycler à proprement parler, pour que de nouveau il soit susceptible de jouer ce rôle très complexe, extraordinairement important pour l'homme, qu'il a à jouer.

Pour continuer ce qui vient de nous être dit par le Dr. Callahan, nous prendrons d'abord le rôle du sol comme support d'éléments à recycler. Certains de ces éléments à recycler apparaissent à la surface du sol sous forme liquide, contenant des corps en dissolution en très fine suspension, ou en plus grossière suspension. Ces eaux résiduaires, souvent d'industries agricoles, et parfois de zones urbaines peuvent agir sur le sol. Souvent elles peuvent transformer ses propriétés physiques, par exemple par le sodium qu'elles contiennent en solution qui diminue la perméabilité du sol; ou les conditions des sous-developpements biologiques par la masse d'eau qui est apportée au sol et qui peut provoquer des réactions anaérobies dangereuses pour la vie du sol et pour le maintien de ses qualités; ou les éléments par ses caractéristiques chimiques tels des oligoéléments apportés en quantités trop importantes par l'eau. Deux catégories d'éléments sont particulièrement importantes dans le cas qui nous occupe, certains produits azotés, ou au contraire carbonés trop pauvres en azote, dont l'accumulation risque de modifier l'activité microbienne du sol; et, peut-être plus encore, certains métaux lourds qui, apportés en excès, peuvent devenir toxiques dans le sol. Il y a aussi, comme le disait tout à l'heure notre collègue le Dr. Callahan, et je n'insisterai pas sur ce point, une action du sol sur les eaux résiduaires, qui sont ainsi plus ou moins totalement purifiées. Enfin, les éléments solides les plus grossiers qui sont déposés viennent modifier les conditions du sol, on pourrait presque dire de la même façon que les modifieront les gadoues et composts qui pourront être apportés. Car, en effet, à côté des éléments liquides qui sont à recycler sur le sol, il en est d'autres qui sont des éléments solides, en particulier les ordures ménagères: rien qu'en France, cela représente déjà onze millions de tonnes par an. Une partie de ces gadoues et ordures ménagères sont biodégradables, à cause de leur nature organique, et peuvent donc être plus ou moins facilement recyclées sur le sol, après les tris et les stockages contrôlés. L'épandage est la meilleure méthode pour réutiliser ces gadoues et ces composts. Cette utilisation pose cependant un certain nombre de problèmes. C'est dans le cas de ces apports de gadoues et de composts que l'on observe souvent des phénomènes de blocage de l'azote ou bien des apports en excès d'éléments métalliques qui, généralement, ne sont que des éléments-traces, et qui finissent par être, dans un certain nombre de cas, en quantités très excessives.

L'apport de ces eaux résiduaires et de ces gadoues sur le sol ne doit pas être fait de façon incontrôlée. Pour éviter un excès de tel ou tel élément—j'ai parlé de l'azote, dans d'autres cas cela peut être la potasse, l'acide phosphorique, etc.—qui deviendrait en quantité nocif pour le sol, il faut aménager des zones d'apport de façon à ce que les cultures faites dessus puissent utiliser la plus grande partie des éléments qui sont ainsi ajoutés au sol. L'expérience faite aux Etats-Unis, au service de recherches agronomiques si connu de Beltsville et qui nous a été rapportée par le Dr. Walker, est particulièrement intéressante. Elle tend en effet à fixer pour des gadoues d'un type déterminé, pour un sol de caractéristiques déterminées, les quantités optimum que l'on peut utiliser, qui donneront un maximum un rendement des cultures, sans que les propriétés du sol soient détériorées, c'est-à-dire en les maintenant telles que, dans les années qui viennent, le sol puisse continuer à jouer le rôle que nous avons besoin qu'il joue pour nous. Parmi les orateurs, celui qui a présenté spécialement ce problème des eaux résiduaires et des gadoues était le Professeur Hénin, actuellement président de l'Académie d'Agriculture de France. En remplacement du Dr. Greenland, de Grande-Bretagne, qui au dernier moment n'a pas pu venir, le Dr. Vielle, de la Recherche Agronomique, a discuté l'évolution des herbicides et pesticides dans le sol. Vous savez qu'à l'heure actuelle, dans tout système agricole suffisamment moderne et économiquement compétitif, les quantités d'herbicides et de pesticides utilisés sont importantes. Or on considère qu'au moins 50% arrivent finalement au sol. Certains de ces corps toxiques pour nombre de plantes et de micro-organismes, sont entraînés plus ou moins rapidement dans le sol, étant eux-mêmes assez solubles, comme par exemple un herbicide, l'atrasine. D'autres au contraire sont fixés par le sol. Dans la plupart des cas, ces corps ont tendance plus ou moins rapidement à être transformés soit par une action de photolyse pour ceux qui restent à la surface du sol, soit par une action de dégradation biochimique par les micro-organismes du sol. La plupart d'entre eux ont donc tendance à ne pas rester dans le sol: leurs résidus, généralement inactifs. Il en est cependant quelques-uns dont l'utilisation en agriculture a du être défendue. Leur maintien, par exemple, dans le cas des organochlorés peut être trop important, trop long et risque d'être néfaste au sol et à ses micro-organismes. Ils peuvent aussi être entraînés jusque dans les nappes phréatiques sans être détruits, dégradés par le sol.

Enfin, un dernier aspect nous est apparu, mais qui n'a pu qu'être signalé, le temps nous ayant manqué pour le discuter suffisamment, c'est celui du recyclage du sol lui-même. Il est bien certain qu'année après année, de grandes étendues de sol disparaissent de leur fonction primitive car elles ont été reprises par l'homme pour y construire des habitations, des bâtiments industriels, des routes, des aéroports, etc. Et malheureusement, c'est l'agronome que je suis qui le souligne—ce sont bien souvent de très bons sols, extrêmement productifs qui sont ainsi rendus inertes. Il n'est pas question d'éviter cette disparition des sols. Mais ce qu'il faut, c'est—dans toute la mesure du possible—limiter ces pertes et éviter tous les autres types de disparition du sol.

Il y a disparition du sol par l'érosion, très développée dans certains pays mais il y a aussi—et c'est ce qui nous intéresse peut-être le plus dans le cas de ces phénomènes de recyclage—trop souvent disparition excessive du sol lors de mise en place de carrières, d'exploitations à ciel ouvert ou au long des travaux publics, des routes, etc. Il est indispensable que toutes ces surfaces de sol soient récupérées aussi rapidement que possible. Bien sûr, on peut laisser faire la nature. Dans certains cas, il suffira de cinq à dix ans, par

exemple sur les fonds de carrière de terre à briques de la région parisienne; dans d'autres cas, par exemple sur les crassiers de schiste ardoisiers de l'Ouest de la France, il faudra au moins un siècle, peut-être un siècle et demi ou davantage, d'après les observations que nous avons pu faire. L'homme peut accélérer le phénomène. Il le peut par deux méthodes différentes utilisées selon les cas. Quand le sol décapé ou le matériau en-dessous du sol enlevé n'a pas de trop mauvaises propriétés physiques, par exemple un fond de carrière de terre à briques, il peut suffire de quelques apports de matières organiques, d'engrais et du travail de sol pour qu'au bout de deux ou trois ans, un nouveau sol se soit reformé, susceptible de porter des cultures. Lorsque l'on a au contraire affaire à des carrières de matériaux rocheux, par exemple dans les pays tropicaux les carrières où l'on exploite les cuirasses d'oxyde de fer, d'aluminium, de cobalt, de nickel, etc., il est évident que ce qui reste finalement est aussi généralement un matériau rocheux. Il peut aussi y avoir dans ce cas un excès de certains produits chimiques qui finissent par être néfastes par eux-mêmes, tels que ces métaux lourds comme le cobalt, le nickel, le chrome, etc., ou par provoquer certains déséquilibres dans l'alimentation des plantes comme ceux dûs à des excès de magnésium ou au contraire de calcium. Il est évident que refaire un sol dans ces conditions est beaucoup plus difficile.

Des expériences sont en cours qui montrent que l'on peut quand même y arriver, par des apports de matière organique en grande quantité et, le cas échéant, par des apports de gadoues, ainsi que par des apports d'engrais en grande quantité pour rééquilibrer le sol dans la mesure du possible. Ce n'est pas dès la première année que l'on pourra espérer obtenir des récoltes vraiment profitables. Généralement, on commence par refaire la structure du sol en y cultivant des graminées adaptées, ou d'autres plantes rustiques à système racinaire fasciculé et capable de descendre assez profondément; au bout de deux ou trois ans, on peut y installer des arbustes et des arbres absolument indispensables pour maintenir le matériau et faciliter sa transformation. Ils sont variables, bien sûr, en fonction des conditions écologiques du lieu et des éléments plus ou moins toxiques qui se trouvent dans le sol. Souvent ce sont des pins, des acacias, des robiniers, des cassis, etc. Voilà, résumé aussi rapidement que je l'ai pu, ce que nous avons eu à présenter sur ce problème du sol et ce que la discussion nous a apporté. Retenons ceci: c'est que le sol est un élément essentiel, une ressource naturelle qui ne peut pas être remplacée par une autre; il nous le faut, ne serait-ce que pour pouvoir maintenir la végétation et utiliser l'énergie solaire: il faut éviter de le laisser se dégrader et plus encore de le laisser disparaître; chaque fois qu'il est possible, il faut le recycler, et comme il a déjà été dit pour d'autres ressources, il faut chercher à mieux connaître l'étendue des sols utilisables, leurs caractéristiques, leur mode d'évolution, les meilleures méthodes que l'homme peut appliquer pour les utiliser en vue de son bien, tout en maintenant leur niveau de fertilité.

BROWN: Thank you very much. I now open the floor for discussion of these two papers.

RICHARDSON: Without at all detracting from the point of the focus of the discussion up to this point; I think the very different perspective of the water studies in the United States and the kinds of concerns which characterize in particular south Asia, Latin America, and Africa ought to be emphasized. In the latter case the concern is how to get enough water to avoid famine next year. In this regard the critical issue seems to be capital requirements to meet this very basic need. We have attempted in an aggregate way to model the prob- lem of making alternative allocations in these three critically water-short regions. In addition to the first point I should like to emphasize the extreme paucity of data necessary even to make the grossest estimates about issues of agricultural policy involving the trade-off of capital investment between irrigation, for example mechanization, investment, and fertilizer. I should like to suggest, while it is obviously essential, that con- siderations of recycling and the preservation of soil and the use of advanced technology and the charging of aquafers and the like be taken into account; that it is highly unlikely that it will be done by nations who are concerned now with how to get enough water to feed their population a minimal subsistence level next year. That there ought to be attention devoted to how the capital requirements can be provided to achieve at least that minimal level of water as well as making the judgments for more effective policy and hopefully providing a setting in the future where these more costly as well as sophisticated considerations can be taken into account.

WEBER: I want to make a short comment on Mr. Callahan's explanation about recycling of water, which I consider to be an interesting example of research into water recycling. You know that cooling water from atomic energy plants conducted to rivers increases the water temperature, decreases water quality, and causes eutrophic conditions. Such conducting is very dangerous in summertime when running water has higher temperature than usual. For this reason the hot cooling water is injected into permeable rocks from these plants during summer. This water remains in the underground until winter and is then pumped to a river in which the water is relatively cold during this season. It increases the water temperature, which is, however, of little importance to the biological system of the river during winter time.

CALLAHAN: Perhaps this is a professional subject that we could take up at another time, but we in the Survey are now trying to model this particular system to try to find out just how efficient a storage container the earth would be for storing this heated water, because as you say, hot water in streams is a problem in certain seasons. If we can store it in the ground it is usable at a later time and it saves energy.

AUBERT: J'ai été très intéressé par la remarque qui a été faite par notre collègue au sujet de la situation critique de la zone sahélienne d'Afrique. C'est un problème pour lequel j'ai eu moi-même à travailler, non seulement ces deux ou trois dernières années, mais déjà en 1947–8. C'est un pro[illegible] et

peut-être aurai-je la possibilité d'en discuter personnellement avec notre collègue; c'est non seulement un problème technique bien sûr, mais aussi un problème humain. Il s'agit de savoir où est l'eau, comment la pomper, comment l'utiliser, comment faire la part entre ce qu'il faut pour l'homme, pour la boisson, pour les animaux et ce que l'on peut garder pour essayer, dans la mesure où la population s'y prête, de faire de la culture arrosée, sinon irriguée, tout en conservant quand même le sol et la végétation autour des points d'eau. Je vous avoue que ce que nous avons fait dans le nord du Sénégal il y a vingt ans maintenant n'a pas toujours été un très beau succès, loin de là. C'est un problème d'autant plus difficile qu'il a un aspect social et que ce que l'on peut faire dans un cas déterminé avec un type déterminé de population, par exemple si vous avez surtout des Peuhls, ne sera probablement pas possible si vous avez un autre type de population dans une autre région de la même bande sahélienne, par exemple des Sara ou des Bembaras. Ce problème est loin d'être résolu, mais il est important qu'il ait été soulevé.

LINDBECK: Is it possible to add a point to the already discussed question of minerals?

BROWN: Yes; there are many people who want to discuss that, I know. I propose that we go ahead with our last speaker and then come back to this, if that is agreeable to you.

BRENDOW: I feel that the discussion on the water problem suffers from the same deficiencies that suffered the discussion earlier this afternoon on minerals; namely, a lack of coordination between the working groups. Some of the results in the working group in which I had the honor to participate—the one on energy—are of importance also for the discussion on the water problem and I have no doubt they would have influenced heavily the report given to us. I refer to a lesson we received from our colleague Kellogg, on the heating up of the atmosphere in the long run due to increased use of energy. If I understood him correctly, his feeling was that there would be a warming up of the atmosphere with increased clouds and rainfall—in other words a new equilibrium in the water economy of the world. I would—naively maybe—deduct that the concern about the long term water availabilities would be lesser than it seemed to appear from the report we just received. It was also indicated to us that due to the increased rainfall in the long term the growing season might be extended by another 10 days, which has quite obviously an important impact on agriculture and the nutrition of world populations. I mention this, hoping that I rightly got the message and inviting all my colleagues here to please play the role of a coordinating body between the various working sessions because there is no use if one working group comes forward with one message and tomorrow morning we will receive another message.

BROWN: Thank you. As I mentioned earlier in the discussion, I feel that these two groups which were separated from the very beginning, which is unfortunate, and time has been very limited. . . .

DOSTROVSKY: With a risk of complicating life even more, I want to draw attention to another problem which arises in many parts of the world, and will be increasingly so, where the use of water becomes close to the limits available, and where large scale recycling is practised. I am not quite sure the committee referred to it, but it is quite a serious factor. I refer here to what we call at home "creeping salinity"—it is a phenomenon which is quite easy to understand in chemical engineering terms. It is the equivalent to what would happen if you reduced the blow-down rate from a steam boiler—you are increasing the salt concentration. If you recycle much of your water without having any outlet for it from your particular system, you are going to build up salt in the water. The time constants are not too short and are measured in years, but the ultimate result is devastating. You can really wreck—and permanently so—the whole of your aquafirs. So before advising large scale recycling and high intensity use of water, one has to be very, very careful that one knows what one is doing or the temporary benefit may be converted into a permanent disaster.

CALLAHAN: There is no question of the truth in what you say. The Long Island, New York, experience has already shown the increase in dissolved solids as a result of just recycling through septic tanks. The experiments that I spoke of in Florida are to store freshwater as a bubble in a salt water aquifer.

BROWN: I am afraid I am going to have to move on to the next speaker. I am sorry. I will call on now to Dr. Joy who will report on the environmental effects of waste materials.

JOY: The principle points which arose in the session on the environmental effects of waste were: (1) The impossibility of separating environmental and resource needs (including water and land) from each other. The needs of the whole system have to be optimized for now and for the future. (2) The need to rationalize the production of waste and waste disposal systems. (3) The need to obtain at least semi-quantitative data relating to flows in the system. (4) The need to produce at least approximate cost values both for actual waste disposal costs and for notional costs, i.e., the nondirect monetary costs of damage to the environment or to the cost of not taking sufficient steps to protect the environment. (5) The need to pay particular attention to the possibilities of replacing nonrenewable resources by renewable sources. (6) The need to close recycle loops as early as possible, that is to say that material must, as far as possible, be prevented from escaping from a cycle and return for reprocessing at the earliest possible time and to a point in the circuit where it is most easily accepted by the circuit. (7) There is clearly a difference in opinion between the industrialized countries and the developing countries concerning the relative importances of these problems. (8) The market offered the best promise for control both of resource use and the generation of waste. Most of these points are obvious and far from new. However, we thought it was worthwhile examining them in greater detail. It was clear from the descriptions of the large number of different processes at present operating, planned and under investigation, that there is a large number of options open to anyone wishing to reprocess wastes.

The options also include abilities to decide the functions of the processing in order to meet particular requirements, that is to say, there is a very wide range of flexibility currently available. With the improvements and new processes under development, it can be expected that a feasible process should soon be available to meet almost any particular requirement. These processes, however, range from very simple disposal of the waste with the object of doing it as cheaply and/or as efficiently as possible, to complex processes aimed at almost total recovery. The criteria on which decisions to select any particular process are made depend, of course, initially on the nature of the waste, but for any particular waste the subsequent criteria seem to be highly variable and depend upon such factors such as national, local, and even personal attitudes. Plain salesmanship and publicity can play an inordinately large part. The influence of public opinion and legislation was also thought to leave very much to be desired in relation to both the magnitude and the point of application in governing the criteria. A logical approach was recognized as being desirable. One speaker stated that he thought even a semi-quantitative yardstick was better than none. Four of the papers presented had this general, overall objective in view, but in themselves the approaches so far suggested are inadequate without a wider range of data to enable them to be refined to the point of applicability. Some aspects of the approaches also require data which may not be available, and may need to be inferred, thus introducing all the dangers inherent in the application of the results of such calculations. However, there is much actual data which can be obtained, particularly for the mass flows and costs of straightforward domestic treatment and for single recycle loops in a particular plant. The strengths and weaknesses of the applications of a systems approach to the problem will undoubtedly become much clearer once a few trial syntheses have been made. Attention was also drawn to the possible adverse effects of excessive pollution control both on the economy and on the actual environment. The point was also made that excessive preoccupation with recovery and waste treatment plant development and construction could lead to a situation where waste would have to be created in order to ensure continuation of the consequently vastly enlarged recovery and reprocessing industries. This is not impossible, and also points to the need for even a crude predictive model to ensure a balance between the input (control of the production of waste) and the output (retreatment and recycling) points of the system. The views expressed by the representatives of the developing countries were not unexpected, especially since the majority of such countries are also the major actual or potential sources of raw materials supply. The attitude is justifiable in that by the time that they themselves become major users it should be expected that solutions to the consumer waste, environmental disposal, and resource supply problems may have been found and tested in practice by the present consumer nations. This is less justifiable in relation to the environmental aspects of winning and of primary processing. It is again clear that traditional methods for process selection and plant design and operation, based only on optimization of grades and recovery, in relation to the process cost (the overall rentability of the operation) will have to give way to a systems approach in which the aim is to optimize the complex interaction of grade, recovery, process costs, environmental costs, and population and/or employment needs. Employment is currently an important factor in process design for developing countries, but the factors of environmental significance have not yet been fully appreciated since they tend to be notional rather than observable costs.

Thus, the general consensus is that both technological advances and commercial awareness in relation to environmental problems were making satisfactory progress, but that need existed for wider appreciation and understanding of the associated economic social and political factors. Finally, there was unanimous agreement that the final stage, the point where the finished product is marketed, is the most sensitive area for any experimentation in the reduction of the overall effects of human activities on the environment and on resources.

HERBERT: My comments have to do with the second suggestion that was read which relates to the household segregation of wastes to at least two categories: I would like to suggest that we qualify that statement. Basically this is a myth that is being promulgated by a lot of people who are well-intentioned but ill-informed, about the garbage-collection business, the secondary fiber business, and the wastepaper business—I mention those because primarily you are normally talking about newsprint segregations. If everybody in the United States were to save their newsprint we would have the darndest piles of newsprint on the dumps than you have ever seen. The market is broad but it is finite. If you collect more than the market can consume, it is just simply going to go to the dump or to the incinerator anyway. This happened in many cities and a lot of people become very much discouraged. Hence I would like to suggest that we qualify that suggestion by saying "where finite markets exist for the segregated product." I think it is very important that we do not tell everybody in the world that they should save commodities for which a market may not and frequently does not exist.

DYKE: Two years ago I attended the Stockholm conference on human environment. At that time I was faced, on the one hand, with the prophets of doom and, on the other, with the assurances that all will be well, and that in the end man will find a way. Immediately after Stockholm I set out as a technologist in waste management on a definite plan of research at my own expense in an effort to prove the prophets of doom wrong. I have to admit that I have not yet succeeded in this. I have studied most of the major technologies in hand and at pilot stage, designed to deal with the recycling of waste—mainly as to the municipal solid waste products. From this study I am coming to the conclusion that I may have been following the wrong track. Much of the technology is at high cost, and in many instances the investment required in monetary

and energy terms may not satisfy the cost-benefit ratio. I am now looking for low cost technology in the recycling area and in fact I have to go back over my tracks to discover first of all how the heap of garbage I have been looking at has in fact accumulated. I believe our first task is to study wasteful practice all along the line from the primary source area through the design production and utility area to the final waste. And the energy equation must preferably be the first reference. When I have discovered the best means of waste avoidance so as to reduce the pile of garbage to the absolute minimum, then I will be able to determine the best technology and practice necessary to handle the recycling of the final and unavoidable waste product. What I am in fact saying is that it may be wrong to look at our heap of garbage as it is. Perhaps we should first study how best to produce a smaller heap. On one point made by Mr. Joy as to technology designed to accommodate waste, it may be proved we shall need a certain waste product to feed the technology applied. Another point: is there any advantage in producing a car that will last 20 years if at the end of 10 years I am fed up with it and push it over the cliff?

Might it not be better to design the car and a reclamation process for the end product after use that would in effect get the remaining resources back into the supply stream and at an overall preferred social economic cost this could apply to all forms of waste and post-utility objects. In other words, we have got to look at primary extraction, utility, design and production through to the final waste product which must be minimized—or maximized? We do not yet know before we apply the technology needed to recover the waste.

JOY: Taking Mr. Herbert's remarks first. I was not aware that I had actually recommended the selective collection of domestic refuse at any of the points. I think the point Mr. Herbert was commenting on was the need to rationalize the waste production, collection, and disposal. I certainly not had the intention of making a categorical statement that I really thought that for domestic refuse collection, selective sorting at the source was necessarily the best. As far as Mr. Dyke is concerned, he has made three statements which I was very pleased to hear. He referred to the energy equation and asked whether we ought not to look at the cost-benefit ratio. You cannot achieve this cost-benefit ratio assessment nor optimize the energy equation unless you are prepared to introduce the environmental effects; the title of this session was "The environmental (not the economic) effects of wastes." As I said before, in a balanced economy and in a balanced world they have got to be taken together. So the cost-benefit ratio and the energy balance must include some, even only notional guesswork, costs to put in either as a debit, or, if the situation is that the waste has to be processed for environmental reasons, to consider it as a profit and put it on the other side of the equation. The same goes for the energy equation. You may have to say: "Am I prepared to expend the effort on a polluted river or would I rather have the energy available for some other purpose?" That brings me to Mr. Dyke's two other statements, his "mights" and "ought he nots": the point is that even after all these years of expertise he is still (and for that matter so is anyone else) in the position of not knowing. The reason is the tremendous complexity of the whole waste recycle, rejection return, and production route, and the lack of any systematic data including notional costs. There is not nearly enough quantitative thinking and quantitative data for successful planning.

BROWN: I notice it is almost adjournment time. In order to end the meeting and provide a grand finale, the chair is prepared to entertain the question of Dr. Lindbeck concerning the availability of resources.

LINDBECK: My interpretation of the rather pessimistic exposition about minerals in the report is that it is based on three assumptions. The first assumption is that the use of energy will rise very rapidly per unit of minerals produced when we move to more expensive deposits. Obviously, there is here an assumption about unchanged technology because the speaker said that there was an exponential increase in energy cost with falling quality of the deposits. But if there is such an exponential function, that function must shift downwards because of continuous technological development. The combined *movement along* the curve and the *shifts* from one curve to another could very well be a *fall* in the cost. This seems, in fact, to have happened for many minerals over time.

A second assumption must have been that energy prices will rise *very rapidly* in the future. I am most convinced that this is true. Moreover, we have to consider that energy costs are not more than maybe 5% of GNP. So to get real substantial effects, maybe you need an increase of 10, 15, or perhaps 100 times the present costs, until you get really drastic effects on GNP growth *in a long-run perspective.*

A third assumption was that if raw-material prices rise rapidly, because of higher energy costs of extraction, there will be "severe problems." I do not see why this would be so serious in a 100-year perspective because of all the various substitutions on the production and consumption side we talked about this morning. In fact, you could conceive of a civilization, 100 or 500 years from now, where most metals used in the production process are produced by recycling. This could occur in a situation where demand continuously shifts to less resource-requiring activities, such as services, and where productivity increases mean that commodities require less and less materials. On *all* these three points I am very little convinced about the "pessimistic" assumptions made in the presentation.

SHELDON: I shall attempt to make remarks on that. I do not know that I can answer it. First of all, in the study of the exponential increase in the energy costs for producing, mining, and milling ores of lower and lower grade, the study that has been made so far is based on constant technology and it is a study at this moment in time and is based on the energy costs of a number of different mines and a number of different commodities. Of course, with an increase in technology aimed in this direction, you can lower the energy

costs a certain amount. But still the fundamental underlying cause of exponential rise is the actual energy costs of moving rock and breaking the chemical bonds of the minerals. No amount of technology and technologic research can overcome the basic physical laws of the universe. In so far as the model I suggested, as I stated it was intuitive and it was based on present trends. It is certainly only one of an infinite number of scenarios. I think if the trends continue of exponentially increasing population and all the rest, that something like that is probably going to happen.

BROWN: I am confident that this subject is going to come up again tomorrow.

Chapter V

LONG RANGE ENERGETIC RESOURCES AND GROWTH

Président: G. RANDERS

CONTENTS

RAPPORT DU GROUPE LES RESSOURCES ÉNERGÉTIQUES À LONG TERME ET LA CROISSANCE

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Nous avons eu quelques vingt communications. Nous avons travaillé près de 14 heures et je sens que je pourrais être très vite horriblement ennuyeux. Je ne ferai donc pas ce que vous attendez peut-être, c'est-à dire extraire les idées principales des communications et des discussions de ces 14 heures. Car un certain nombre de ces idées, malgré leur importance, sont celles qui regardent les spécialistes de l'énergie proprement dite. Et ici, je crois beaucoup plus important de rappeler dans ce qui a été dit, ce qui a un caractère interdisciplinaire. A mon très grand regret, je ne vous parlerai donc pas des aspects spéciaux de l'énergie nucléaire qui ont cependant été traités à fond, ni de ceux de l'énergie thermique, géothermique ou solaire mais je vous parlerai de ce qui peut avoir une influence sur les conclusions des autres réunions qui se sont poursuivies en parallèle avec nous.

La futurologie est révélatrice d'un certain nombre de gros problèmes. C'est presque toujours à travers elle que l'humanité manifeste son souci de mutation, son souci de révolution ou de changement. Je ne donnerai pas des exemples, vous les avez tous en tête et il vous serait facile de développer ce point: je me bornerai à un seul amusant: l'énergie a créé la futurologie, c'est à propos d'elle que l'on a commencé à faire des prévisions puis ensuite des scénarios.

Point important: un accord était-il possible sur la façon dont va probablement évoluer l'utilisation des sources actuelles ou futures d'énergie? Et ceci, je tiens à le préciser, d'une façon très indépendante de l'évolution des besoins. Naturellement, on ne peut pas pousser cette séparation jusqu'au bout sans paradoxe, l'évolution des besoins fixera la cadence avec laquelle les substitutions éventuelles se feront, mais probablement, n'influencera que peu les choix successifs.

Tout le monde, je pense, est d'accord sur le fait que les deux grandes aventures énergétiques en cours pour l'arrivée du XXIème siècle sont, d'une part, les surgénérateurs, d'autre part les réacteurs à haute température.

D'abord, les surgénérateurs. C'est une chose absolument extraordinaire et hier matin en écoutant vos propos, par exemple sur les substitutions, je ne pouvais m'empêcher de penser aux propriétés que présente la substitution, des surgénérateurs aux réacteurs nucléaires actuels. Vous savez qu'ils vont permettre d'obtenir un rendement en uranium pratiquement de l'ordre de 50 à 70 fois le rendement actuel. Aussi quand 'jécoutais hier des propos un peu désabusés sur la substitution, je me consolais en pensant qu'évidemment, pour le

moment la surgénération est la seule technique de substitution qui d'un coup permet d'obtenir 70 fois plus d'énergie de la même portion de matière. Et si vous tenez compte du fait que cette portion d'énergie sera obtenue avec 70 fois moins de peine, en ce qui concerne l'extraction vous imaginez qu'on pourra extraire maintenant des minerais à teneur peut-être 70 fois plus faible, ce qui permettrait de penser que la substitution éventuelle et très probable des surgénérateurs correspond à une amélioration dans le bilan de l'énergie de 1 à 5000. La puissance de l'esprit de l'homme ne doit jamais être sous-estimée, une fois les surgénérateurs en route—(et ils ne peuvent guère l'être commercialement de façon importante avant l'an 2000), l'énergie électrique deviendra un sous-produit des autres activités industrielles, le fonctionnement d'un surgénérateur pour produire de l'électricité assurant par là même la production des matières fissiles permettant dans un second cycle de produire à nouveau de l'électricité. *L'électricité devient maintenant un sous-produit de l'activité industrielle.*

Les réacteurs à haute température sont aussi une grande aventure. En effet, les seuls réacteurs capables de donner de la chaleur à haute température sont ces réacteurs que l'on appelle H.T.R. dans toutes les langues. Dès maintenant, un réacteur d'essai a dépassé 850 degrés en Allemagne, ses propriétés, grâce à l'utilisation de l'hélium, suppriment une grande partie des objections que l'on fait encore pour les structures. Ils permettront, par la production de chaleur à partir du nucléaire, de dépasser le cadre restreint de l'électricité et, de remplacer à long terme les combustibles fossiles, en particulier le pétrole. Dès maintenant, nous sommes assurés soit par la version américaine de ce réacteur, soit par la version européenne essentiellement allemande d'ailleurs, pour le moment, d'avoir dans un délai relativement bref (10, 15 ou 20 ans) la possibilité de fabrication de chaleur à des températures élevées et l'une des possibilités les plus étonnantes réside dans la fabrication de l'hydrogène.

On a pu, dans un élan d'enthousiasme, parler de l'avenir comme de celui de la civilisation de l'hydrogène—notre ami Caprioglio qui est à cette table à droite aura certainement l'occasion ce matin de vous en parler avec enthousiasme—il y a quelques mois nous étions quelques-uns ici à assister à Miami, parmi huit ou neuf cents personnes, à cent ou cent cinquante communications. L'enthousiasme était tempéré par quelques producteurs de machines électriques ou d'électricité qui, naturellement, ne désirent pas voir dans un délai trop bref tout leur acquis devenir "obsolète". Ils ont d'ailleurs certainement tort de le craindre; ainsi l'EDF attend sans inquiétude l'avènement de l'hydrogène, ce fluide étant complémentaire de l'électricité et non pas son ennemi.

Les difficultés sont encore très grandes pour obtenir une production d'hydrogène à bon marché. Les gens optimistes mais raisonnables estiment qu'il faut encore 15 ou 20 ans et par conséquent, c'est vers l'an 2000 que nous pourrons voir l'hydrogène prendre sa place: l'automobile, à condition de résoudre le problème de la combustion dans l'air sans oxyde d'azote, l'aviation, les usages domestiques. J'ai toujours plaisir à dire que quelqu'un m'a dit que la seule application que l'hydrogène ne peut pas résoudre, c'est le rasoir électrique, et j'ai oublié pourquoi.

Ces deux nouveautés, ces deux aventures, nous sommes en train de les courir au point de vue énergétique, avec de grandes chances de succès: les surgénérateurs et l'hydrogène.

Mais un certain nombre de problèmes sont posés par la prolifération du nucléaire et ceux-ci peuvent rendre nécessaire l'arrivée de sources nouvelles, bien avant que les problèmes économiques ou que les problèmes de rareté ou de pénurie interviennent. Je ne pense pas du tout au problème des radiations—je suis personnellement depuis vingt ans

spécialiste de l'atome, j'ai même eu la chance de présider à la construction complète d'une centrale en Espagne de 500 000 kW—je ne crois pas réellement que, sauf accident—toujours possible—, nous ayons à être préoccupés par ces problèmes.

Je pense essentiellement puisqu'il s'agit de surgénérateurs, au problème du plutonium. Il est certain que le plutonium est dangereux et que un millième de milligramme inhalé de façon convenable dans le corps peut être mortel. Les tonnes de plutonium qu'un pays comme la France, par exemple, manipulera en l'an 2000, avec l'arrivée des surgénérateurs, représente donc des potentialités mortelles prodigieuses. Naturellement, on sait prendre dès maintenant toutes les précautions nécessaires dans les différentes manipulations et dans les transports. Mais dans le monde où nous vivons, où la violence est de plus en plus maîtresse d'elle-même, où l'on sait que "le pouvoir est au bout du fusil", on ne peut être assuré que le plutonium, quand on le traitera par centaines de tonnes, ne donnera pas naissance à des tentations irrésistibles. Monsieur Lewis dans sa communication a cité pour défendre le plutonium, une phrase, très impressionnante d'ailleurs, de Soljenitzine à propos de la violence: "La violence est inéluctablement liée au mensonge; dès que celui-ci aura disparu, la nudité sordide de la violence sera visible et la violence deviendra impuissance". Eh bien, je fais le voeu qu'il en soit ainsi, mais je me demande s'il ne sera tout de même pas plus facile de supprimer la violence que de supprimer le mensonge.

Donc nous avons, je le disais au Président Marois tout à l'heure, dans nos travaux à ne pas oublier ce problème: les hommes sont de chair et de sang et ils ne renonceront jamais à utiliser leur force ou leur intelligence pour obtenir des résultats qu'à tort ou à raison, de bonne ou de mauvaise foi, ils estimeront devoir obtenir. Nous devons naturellement lutter pour qu'il n'en soit pas ainsi, mais nous ne devons pas offrir trop de tentations sans être un peu responsables. Je me sens donc obligé de vous parler de sources nouvelles que j'appelle d'ailleurs sources lointaines; ainsi personne ne se fera d'illusion sur le fait que ces problèmes se poseront seulement dans les premières décennies du vingt-et-unième siècle: l'énergie géothermique, énergie non renouvelable, car nous ne pouvons utiliser que l'énergie qui est dans les profondeurs, jusqu'à quelques kilomètres en-dessous de nous, par exemple, et quand nous l'aurons épuisée, elle mettra des millénaires pour être reconstituée; en fait, nous pourrons l'utiliser sur cinquante ans, soixante-quinze ans et après elle aura disparu exactement comme un gisement de charbon.

Il y a l'énergie solaire, nous en avons beaucoup parlé, il faut en reparler, car elle est très importante mais très diluée. Enfin, il y a l'énergie de fusion qui, par collage de deux particules, perdant du poids par ce collage, dégage de l'énergie. Cette fusion a maintenant deux variantes: l'ancienne que l'on étudie depuis vingt ans, qui pas à pas s'approche de sa solution: lentement, le confinement magnétique et l'explosion, faible bien sûr pour pouvoir la contenir dans un récipient. On fait des explosions durant des micro-secondes, mais d'une façon suffisamment fréquente pour que, comme dans un moteur à explosion, nous puissions recueillir l'énergie; ceci paraît possible grâce à l'application des lasers.

Voilà donc très rapidement placé le cadre dans lequel nous avons discuté, ajoutant qu'il y a un certain nombre de sources à l'heure actuelle qui ne sont pas utilisées pleinement, qui n'ont pas le caractère d'être nouvelles ou lointaines et auxquelles il faut penser par exemple dans les pays très riches en charbon comme les Etats-Unis ou la Pologne. Il y a tout un monde énergétique en cours de préparation et à côté de cette notion du tout nucléaire/tout hydrogène qui correspond aux pays européens et au Japon, il peut y avoir aussi une civilisation charbon/methanol ou charbon/combustible synthétique aux Etats-Unis.

Tout ceci nous a amenés au sujet plus proprement le vôtre, c'est-à-dire aux besoins, à la croissance économique. Nous avons eu, dans nos discussions sur ce point, l'éventail le plus large que vous pourriez désirer. Si je prends un extrême, nous retrouvons notre ami, Monsieur Lewis, du Canada, qui a pris comme but une augmentation de la consommation actuelle d'environ deux cents fois, estimant d'ailleurs—ce qui est extrêmement rassurant, que ceci pourrait s'obtenir dès les années 2050 sans aucune source nouvelle, sans appui les surgénérateurs, sans recherche sur les H.T.R, simplement en utilisant d'une façon plus complète la filière canadienne dont vous connaissez les succès. Nos amis canadiens, en pleine bonne foi, n'arrivent pas à comprendre comment le monde n'est pas persuadé de cette vérité et comment il se fait qu' aujourd'hui, dans d'autres pays on utilise d'autres filières, mais ce n'est pas un sujet que nous traiterons ici.

Au centre des positions prises dans nos sessions, l'exposé de Monsieur Zracket, de Mitre, l'organisation de recherche et d'études du M.I.T., révèle deux scénarios, l'un modéré et l'autre moins, qui le conduisent en l'an 2100 à 55% ou 70% d'énergie solaire. Je voudrais vous lire quelques passages de ce que Monsier Destival, qui a des responsabilités très importantes au Plan, pense de la croissance de la consommation de l'énergie dans les 25 ou 50 prochaines années. Il estime que les modifications de prix, le quadruplement du prix des combustibles liquides et par conséquent la distorsion considérable qu'elle apporte par rapport aux optima admis jusqu'ici dans les équilibres énergétiques, va progressivement apporter un frein très important à la consommation d'énergie. Pour l'an 2000, alors que beaucoup estimaient que la consommation du monde serait 4 fois la consommation actuelle, il estime que les freins conduiront à une consommation simplement double de la consommation actuelle. Voici les trois facteurs qu'il pense être capables d'infléchir la croissance énergétique, l'évolution des coûts de l'énergie, la saturation de certains besoins, enfin la croissance économique réduite.

1. L'évolution des coûts d'énergie: de 1950 à 1970, les coûts de l'énergie avaient régulièrement diminué en monnaie constante. En France, de 1960 à 1970, 30 à 40% pour les hydrocarbures. Les prix d'aujourd'hui sont, à son avis, beaucoup plus représentatifs de l'économie à long terme que les prix d'autrefois et ils anticipent déjà l'évolution à long terme. Aussi, le parc des appareils et des procédés actuels se trouve très loin de leur optimum économique.

Il faudra des années, des décennies peut-être pour retrouver l'équilibre. Un exemple, le chauffage des logements: les normes d'isolation vont maintenant se trouver profondément modifiées soit par voie autoritaire ou incitative (en France on envisage de dispenser d'impôt les dépenses correspondantes), d'autre part l'augmentation du prix du combustible à elle seule aura une influence considérable, et il estime que pour le chauffage des locaux, on peut arriver à une consommation moitié des consommations actuelles par tête d'habitant. Et ne prenons pas d'autres exemples car après avoir passé en revue les différentes conséquences de ce phénomène, il estime que l'on peut obtenir une réduction de 30% dù mouvement général ce qui correspondrait à une réduction de 1,5% par an du taux de croissance moyen d'ici l'an 2000.

2. Il passe ensuite au deuxième facteur, la saturation de certains besoins.

En analysant la croissance des consommations en France, entre 1960 et 1970, il constate que le total de la consommation a crû de 95% et là-dessus le secteur domestique avait augmenté de 150%, les transports de 220% et l'industrie de seulement 55%. C'est donc la demande des ménages et du tertiaire qui a été la plus dynamique de la croissance énergétique Il pense qu'une certaine saturation intervient déjà: 10% des logements en 1954 avaient le

chauffage central, plus de 50% aujourd'hui et si on est encore loin de la fin, la moitié du chemin est déjà faite.

De même, il pense que le secteur des transports qui correspond aux deux tiers de la consommation connaîtra à court terme un ralentissement, car la proportion des ménages équipés de véhicules était de 30% en 1960, de 70% aujourd'hui. Les Etats-Unis montrent que l'on plafonne aux environs de 90%. Donc tenant compte du fait que l'élasticité énergie/production pour l'industrie a été de l'ordre de 0,6 sur cette période, on peut estimer que là encore nous avons un frein puissant à la consommation, à l'augmentation de consommation énergétique.

Passons maintenant à l'influence de la croissance économique. Sans faire l'hypothèse d'une révolution avec une croissance zéro, il paraît impossible que celle-ci puisse se poursuivre au rythme actuel, car elle a été soutenue par une croissance forte et régulière de la productivité du travail. Les esquisses qui ont été faites pour 1990, pour la France, en prenant en compte l'incidence de l'évolution des facteurs de production, montrent que le taux de croissance pourrait alors diminuer d'un demi-point à un point et demi. En outre, à côté du type actuel de croissance dont le moteur est le développement industriel ou la consommation d'énergie, il est vraisemblable que cette croissance fera une place de plus en plus large à des activités exigeant un faible contenu énergétique.

3. Enfin, la demande énergétique des transports, j'ai quelque difficulté à le suivre ici, freinée par le développement des moyens d'information, radiophone, télé-conférences et transports en commun. Ce qui pose d'une manière générale la question des modes de vie du XXIème siècle et de leurs conséquences sur la consommation d'énergie. Ainsi peut-être, les problèmes de consommation d'énergie n'ont pas l'importance que nous avons tendance à leur attribuer, l'énergie ne sera pas une limite au problème de croissance, les freins automatiques ne conduiront en l'an 2000—si nous le suivons—qu'à un doublement de la consommation actuelle et il n'y aura certainement plus personne pour s'inquiéter de la façon dont ce doublement sera réalisé.

Voici donc une façon originale, et très réfléchie de concevoir le problème des besoins.

Nous avons eu enfin la très grande joie et le très grand plaisir d'entendre le Professeur Dubos nous expliquer que, en biologiste, il estimait que, en consommant moins d'énergie au moins pour certaines classes sociales et certains pays, on obtiendrait une meilleure qualité de la vie.

Son argumentation est très impressionnante et il aura sûrement, je le désire vivement, pour vous et pour moi, l'occasion à nouveau de la développer ce matin. Il remarque qu'il y a des invariants biologiques qui sont les mêmes quels que soient les races, les lieux, les classes sociales et que, quand on s'éloigne de ces invariants biologiques, on s'éloigne de l'optimum. L'excédent de calories que l'européen consomme—3500 par jour au lieu des 2000 nécessaires—est souvent en matières comme le sucre ou les graisses animales dont on pense qu'elles sont génératrices d'innombrables maladies de toutes sortes. Sa deuxième remarque est de constater qu'on a les mêmes résultats avec le soja ou avec la viande de boeuf mais que la consommation d'énergie pour y arriver est 10 fois plus forte dans un cas que dans l'autre.

Il reste à étudier les problèmes climatologiques. Ces problèmes ont d'ailleurs deux faces: l'une d'entre elles a été traitée très à fond par Monsieur Kellogg qui, depuis plusieurs années est spécialiste de ces questions; c'est le problème du climat et des influences éventuelles que les activités de l'homme pourraient avoir sur ce climat. Tout d'abord, une première remarque qui m'a toujours beaucoup impressionné: nous considérons le climat comme une donnée

qui restera constante tout au moins pour nos générations proches et personne n'a parlé d'aller plus loin que l'an 2150. Nous avons tous, au fond de nous, cette conviction absolue que ce climat nous est garanti, qu'il est constitutionnellement dans la Charte des relations entre le créateur et nous; or quand on étudie avec quelque soin le passé, on est terrifié. Nous sommes en ce moment dans une période inter-glaciaire mais rien ne nous prouve qu'une période glaciaire ne peut pas naître demain; et ses actions sur l'homme, sur sa vie, sur son environnement, sur la qualité de sa vie seraient prodigieusement plus graves que tous les points que nous pourrons étudier pendant ces cinq jours de travail, sur l'influence des activités humaines. On constate par exemple un réchauffement depuis 1940, l'année 1945 a été l'année la plus chaude que la terre ait connue depuis mille ans. Quand on sait qu'une période inter-glaciaire ou une période glaciaire, c'est deux ou trois degrés de température en plus ou en moins que; dans un cas le Pôle Nord est libre de glaces ou presque (en tout cas, il l'a été 85% du temps), et dans l'autre les glaces arrivent presque à l'équateur, on est évidemment très impressionné en pensant aux variations naturelles, d'autant plus que, aujourd'hui il n'y a aucun accord—même faible-sur les raisons qui ont pu conduire aux variations de climat dans le passé. En ce moment, nous avons donc une épée de Damoclès suspendue sur notre tête. Nous avons maintenant évidemment à nous poser la question de savoir si nous, n'allons pas nous-mêmes couper le fil de cette épée. Les communications qui nous ont été faites sont assez optimistes. Je ne peux pas ici vous les décrire, même sommairement, la seule indication que je tire du rapport de Monsieur Kellogg est la suivante: à l'heure actuelle, la consommation énergétique dans le monde est de l'ordre de 8000 gigawatts, c'est-à-dire huit milliards de kilowatts et elle représente le 10000ème de l'activité solaire intéressant la terre. Le bon sens fait penser que, on peut donc aujourd'hui être tranquille, c'est l'opinion générale. Mais si nous multiplions, comme le proposait Monsieur Lewis, notre quantité d'énergie par 200, c'est maintenant 200 sur 10000, et 2% sont parfaitement capables de déclencher des modifications de climat; des modèles faits côté américain et côté soviétique semblent montrer que, avec 1% seulement on peut avoir des variations de température moyennes entre 1,5 degré et 3 degrés, lesquels correspondraient par suite de l'influence différente sur les latitudes à une variation de plus de 10 degrés dans les régions polaires: la fusion de l'océan arctique n'aurait heureusement aucune importance puisque par définition la glace flotte, mais les masses très importantes du Groënland représenteraient une élévation de 7 m du niveau des mers, celles de l'antarctique 70 m. Heureusement le changement de climat conduirait à une évaporation beaucoup plus importante des mers actuellement recouvertes par les glaces, par conséquent une quantité de neige encore plus importante tombant sur ces continents et peut-être une surélévation du Groënland. Cette simple remarque vous montre combien les problèmes de climat sont difficiles.

Par contre, et ceci m'a toujours passionné personnellement, si sur le plan de la terre nous sommes encore tout petits, sur le plan local nous ne le sommes plus. La ville de New York envoie vers le ciel, en hiver, aujourd'hui, neuf à dix fois plus de chaleur qu'elle n'en a retenu de l'énergie solaire. Donc nous sommes dix fois plus forts que le facteur essentiel naturel. Nous sommes donc capables de modifier des micro-climats. Ceci n'entraînera pas les conséquences catastrophiques dont nous avons parlé, mais peut apporter sur des régions entières des modifications importantes à connaître. Nous pourrions avoir de véritables petites catastrophes locales si nous installions comme on l'a proposé des concentrations de l'ordre de 50 GW. Quand une centrale thermique fonctionne, elle rejette dans l'atmosphère par l'eau où elle se refroidit, une énergie quatre fois plus grande que ce que produirait dans l'atmosphère la combustion d'une forêt de résineux qui aurait la même surface que l'enceinte

de la centrale, c'est-à-dire y compris le parc à charbon, l'usine, les ateliers, les bureaux du directeur; quand vous visiterez une centrale, qu'elle soit thermique ou nucléaire, pensez à cette image, imaginez une forêt, de la même surface que l'usine, mettez-la en feu et vous aurez là l'image de ce que l'on appelle les *rejets thermiques.* Il y a encore deux pays au monde dans lesquels on crée systématiquement des incendies de forêt pour les étudier: l'Australie, les Etats-Unis. On y met tous les moyens d'observation de variations climatologiques, des avions traversent les nuages: les expériences faites sont au fond très satisfaisantes. En mettant le feu â des forêts qui ont pu brûler une journée ou quelques dizaines d'heures, on n'a pas constaté de troubles météorologiques très importants. De même, il existe au Zaïre un lac de laves en incandescence de quelques hectares, donc l'équivalent d'une centrale de surface; on a beaucoup observé ce qui se passait autour puisqu'il est comparable en rejet à une centrale de production d'énergie: il n'y a rien de vraiment grave. Mais il ne faudrait peut-être pas multiplier cela par 10 ou par 100: telle sera ma conclusion.

DISCUSSION

RANDERS: I want to thank M. Gibrat for his extremely interesting and clear résumé of the section about energy and growth. I am full of admiration for the way in which he was able to give a short and extremely good impression of what was discussed in the two sessions. I noticed that nobody expressed panic or fear that we are walking towards a brink where the world will suddenly break down and perish through lack of energy. On the other hand, everybody agreed that we do not have enough energy to continue with our exponential growth. But, as Gibrat explained, nobody really worried seriously—which was, to me, very surprising, because in some similar conferences you have the feeling that there is a panic—that we are really approaching catastrophe. What surprised me a little is that from an economist's point of view—as was expressed by Gibrat—one got the feeling that the high price of energy is saving us from the catastrophe because that is going to turn the use of energy off a bit, at least turn the increase off. Now to me, this is a slightly dubious interpretation. You might as well look at it the other way; to say that if we have little energy we are forced to suffer high prices. The high prices are the first sign of a shortage of energy. What it boils down to in the end is that so far we have done nothing, one way or the other, to help the situation, and we are simply drifting along. Because there is a certain shortage, prices and political conditions have reached and therefore there is a change in the development. What we are really aiming at in a conference like this is of course to find out if there is anything that we can really do to steer the development—not only drift along and note that nature has taken its course and hopefully will save us. Obviously we will be saved by nature.

The question is whether we move towards a situation which is satisfactory. Our task is really to see if we can do anything to make it more satisfactory instead of less satisfactory. It is a question of degree we are discussing and that's all. For that reason I think it would be important in the following discussions if we keep that aim in mind. We are really looking for what kind of measures and what kind of steps we could take to influence the future a bit. I am saying "a bit" because it is obvious that the future growth of energy will be between the exponential growth until the year 2000—and let us say linear extrapolation from today until the year 2000. In the Ford Foundation report on energy—some of you may have seen it—they have chosen a middle way called the "technical fix" solution. This is a solution, deliberately placed in the middle, which society should try to aim for, instead of letting things run by themselves or believe that one can introduce zero growth already before the year 2000. When we go on to the discussion I should very much like to hear suggestions as to how can we, by our actions today, in any way, influence the future of energy and growth by the decisions we make. I have here at the table specialists whom I want to give the floor during this session. I know there are people in the audience also who want to speak. What I would suggest is that before I give the floor to the audience, I would ask one of the members here to make his comments, and since Professor Dubos is my closest neighbor, I will ask him if he would like to say a few words to begin the discussion.

DUBOS: Hier je crois dans cette salle même ou avant-hier, on a fait allusion au message du Président Nixon alors qu'il était encore Président, message sur l'énergie, et ceux d'entre nous qui ont étudié ce message d'assez près ont remarqué que le Président Nixon n'a parlé que de la production de l'énergie sans même faire allusion à l'utilisation de l'énergie. Au plus il y avait une allusion tout à fait à la fin du message: c'était pour dire qu'il faudrait peut-être diminuer la consommation d'énergie et par là même amoindrir la qualité de la vie. Eh bien, les quelques mots que je voudrais prononcer aujourd'hui ont pour but d'essayer de définir quelle est l'influence de la quantité d'énergie qu'on utilise sur la qualité de la vie humaine. Et pour étudier ce problème, j'ai pensé depuis quelque temps qu'on pourrait l'analyser en trois composantes. Il y a d'abord Monsieur Gibrat y a fait allusion, des invariants de l'espèce humaine et aussi d'ailleurs des invariants de la nature physique qui déterminent d'une façon vraiment très précise combien d'énergie on doit utiliser pour vivre, pour survivre et quel est le coût de cette énergie d'après les endroits où l'on vit. Cela peut se mesurer avec énormément de précision. Ce qui complique un peu la chose, c'est que la façon dont on satisfait ces besoins énergétiques varie énormément d'une culture à l'autre. Pour reprendre très brièvement l'exemple que Monsieur Gibrat a cité tout à l'heure, disons que tous les êtres humains ont besoin exactement de la même quantité de protéines. Il y a des pays où l'on satisfait ses besoins en protéines en utilisant des mélanges de légumineuses. Il y en a d'autres où l'on utilise surtout du porc et du poulet et d'autres comme nos pays, (et comme vous le savez je vis aux Etats-Unis) où l'on essaie de les presque exclusivement en mangeant du boeuf. Eh bien, le coût énergétique de la production satisfaire passe de 1 à 3 à 10 quand on passe des plantes légumineuses au poulet ou au porc et au boeuf. Ce qui complique encore plus les choses, c'est que chaque pays naturellement a des besoins culturels tout à fait indépendants ou plutôt des habitudes culturelles tout à fait indépendantes des besoins biologiques, et qui diffèrent aussi d'un endroit à l'autre. On a fait récemment aux Etats-Unis une étude comparée du coût de l'énergie de la façon dont les gens passent leurs vacances et les différences sont véritablement phénoménales: il y a des gens pour qui les vacances à cause des transports, des déplacements que cela implique, dépensent des quantités d'énergie énormes en comparaison de ceux qui vont simplement se promener autour des endroits où ils vivent. Si bien qu'il est possible d'analyser les besoins d'énergie à partir de ces différentes données. Quand on fait cela, on voit naturellement ce que nous savons tous, que non seulement les pays mais les classes sociales diffèrent énormément. Il est trop évident qu'il y ⅔ de la population du monde qui vivrait beaucoup mieux si on y utilisait plus d'énergie. Ça, tout le monde le sait et je ne vais pas insister davantage, quoique je pourrais là

reprendre le même sujet en montrant qu'il y a des populations pour lesquelles il n'y a pas assez d'alimentation, pour lesquelles les méthodes agricoles deviendraient beaucoup plus effectives si l'on pouvait utiliser de l'énergie, etc. . . . Je n'en parlerai pas, non pas pour l'ignorer, mais au contraire parce que j'espère que tout le monde ici l'accepte à l'avance.

Mais il y a d'autre part des classes sociales et des pays où l'utilisation de l'énergie, de mon point de vue, non seulement n'augmente pas la qualité de la vie mais la diminue énormément et naturellement l'exemple le plus extraordinaire est une grande partie de l'Europe et la plus grande partie des Etats-Unis. Si bien qu'il y a un éventail énorme de "rendement" en qualité de vie de l'utilisation de l'énergie par les hommes. Il y a une loi, je crois, des rendements décroissants, en qualité de vie de l'énergie qui serait assez facile à définir. Je vais simplement, en quelques mots, indiquer pourquoi je suis convaincu que dans un pays comme les Etats-Unis, on pourrait énormément améliorer la qualité de la vie en diminuant la quantité d'énergie par tête; j'ai essayé de diviser cette affirmation en quatre catégories, que je ne ferai que citer et si vous voulez plus tard que je défende mon point de vue, je le ferai en donnant certains exemples et dans certains cas pas mal de chiffres. Je suis persuadé que la santé physique de l'homme, aux Etats-Unis et dans une grande partie des pays européens serait améliorée si on y diminuait la quantité de calories qu'on mange: au lieu de 3500 comme nous le faisons dans les pays européens et américains, nous pourrions vivre beaucoup mieux avec 2500, si on changeait la nature chimique des aliments que nous employons au lieu d'utiliser d'une façon si extravagante les matières grasses et le sucre comme nous le faisons.

Je pourrais aussi parler de la santé psychologique: c'est un sujet très subtil et pourtant assez facile à définir. La façon dont nous utilisons l'énergie dans nos pays dits civilisés nous empêche presque d'entrer en contact direct avec la réalité, nous empêche en vérité de percevoir la réalité physique du monde et par là je crois, je suis certain même, appauvrit notre vie psychologique.

De là, je pourrais passer à l'agriculture. Dans le cas de l'agriculture, il est tout à fait certain que les techniques que nous utilisons dans tous les pays d'influence occidentale sont telles que le rendement énergétique baisse continuellement. On peut facilement démontrer, et cela a été fait dans de récentes études, que la quantité d'énergie qu'on emploie pour produire une quantité donnée de nourriture, quelle qu'elle soit, que ce soit du maïs ou du boeuf, est presque 10 fois plus grande dans des pays comme les Etats-Unis, la Hollande, l'Angleterre, la France, l'Allemagne, qu'elle ne l'est dans des pays où l'agriculture a des méthodes qu'on dit plus primitives, mais qui en réalité sont beaucoup plus efficientes parce qu'elles mettent en jeu le rôle de phénomènes naturels, par exemple tels que la fixation de l'azote par les microbes du sol ou les microbes associés avec les racines des plantes.

Un quatrième sujet que je pourrais discuter, c'est celui de l'architecture, où tout le monde se rend compte maintenant de la folie incroyable qui a engagé les architectes au cours des 50 dernières années à résoudre tous les problèmes de l'environnement humain en pompant de l'énergie pendant l'hiver pour produire de la chaleur, en pompant de l'énergie pendant l'été pour rafraîchir les pièces, alors que l'on savait de tous temps comme le savaient ces anciens architectes sur lesquels on a écrit récemment un livre admirable appelé: "Architecture without architects" ("l'Architecture sans architectes"), en utilisant des ventilations croisées, certaines orientations, certains matériaux de construction, où on peut se permettre d'avoir une vie, un environnement physique extrêmement confortables en dépensant à peu près 4 ou 5 fois moins d'énergie que nous le faisons dans ce bâtiment ici.

Le dernier sujet auquel je ferai simplement allusion, c'est celui de la planification, qui permettrait si on organisait les milieux urbains et les milieux ruraux d'une autre façon, aux gens d'avoir des contacts sociaux beaucoup plus intimes et permettrait par là d'augmenter cet esprit de communauté qui est essentiel à la vie humaine, essentiel à la qualité de la vie et pourrait se faire en utilisant beaucoup moins d'énergie.

Je m'excuse d'avoir présenté tout cela d'une façon très dogmatique, je ne peux que vous affirmer que pour chacune de ces affirmations dogmatiques, j'ai des faits précis et des chiffres précis à donner.

RANDERS: Thank you very much Professor Dubos. I will ask who would like to take the floor?

BROWN: I have been acutely disturbed by this report. Not because it has not been a good report but because there are several very disturbing gaps. First of all, nothing has been said—and apparently you did not discuss at any great length—the distribution and extent of energy resources, which is a major factor and will continue to be a major factor in deciding where mankind is going. Second, the report that I heard dealt almost exclusively with the energy future of the rich countries. Which embraced only one-quarter of the world's population, and which, in another 50 years may well embrace only 15% of the world's population. Third, the report seemed to me to deal with a very long time-scale. I suggest that humanity as a whole is headed for a tremendous crisis on a relatively short time-scale which is intimately involved with the availability of energy. I believe that we are confronted with a convergence of factors and trends which will result in a major crunch for mankind within another 30 years. Which is no further in the future than World War II is in the past. I should like to illustrate this predicament with just a very few observations concerning the world food situation. Food production in the poor countries today barely keeps pace with population growth. Great hopes were expressed for the so-called green revolution, which involves the selection of plants capable of absorbing massive quantities of nutrients and water. Petroleum is necessary for the production of fertilizers. Now, admittedly, we can produce fertilizers using coal. We can produce fertilizers using nuclear energy. But this is in the future. I am speaking of today. Petroleum is necessary to run the pumps which pump the

water for the irrigation, so that one can get two crops instead of one. It is essential that water be applied at the right time. Now, as we all know, the distribution of petroleum is inequitable. Because of this pattern of distribution the recent tremendous increase in the cost of petroleum has affected various parts of the developing world in various ways. Some developing countries have much petroleum and they profit. Others, like China and Colombia, are reasonably self-sufficient at present levels of demand. But there is a very large part of the developing world, embracing about 60 nations, which includes the entire Indian subcontinent and which embraces a population of about 1 billion people, which are extremely hard hit by this situation, and I do not see how they are going to get out of it very easily. At the present time India, as an example, must import petroleum to make fertilizers and she must import fertilizers because she does not make enough herself and she must import food. The price of petroleum is increased by a factor of 4; this has a fantastic effect on the Indian economy. The Japanese have been traditional exporters of fertilizers to most of Asia. The Japanese have made the decision—and quite an understandable one—that with the limited quantities of petroleum available to her which must be entirely imported—they would rather use that energy to make automobiles (which are more profitable) rather than fertilizer (which are less profitable). Therefore in May a large delegation was sent to Peking and another to India, announcing a 15% cut in fertilizer shipments. Superimposed upon this, there is the unknown variable of changing climate. Today we are faced by the fact that the United States, Canada, and to a lesser extent Australia and New Zealand, are the only major exporters of cereal. Superimposed upon that there is this seemingly inexorable trend of people eating more and more meat. We see this in all of Europe. We see this in Japan. America seems to be saturated. It takes 10 or so calories of grain to produce a calorie of meat. Again, this is intimately related to the distribution and availability of energy resources. I suggest that the convergence of these various factors may produce a fantastic crisis for humanity on a relatively short time-scale. I did miss in your report any feeling of urgency from this point of view.

BRENDOW: Let me first briefly react on the last speaker's intervention. I felt that the time horizon of our discussions is not the short term, but the long term. The year 2000—for me—was the earliest year to start with. Secondly, I would like to respond to your invitation, Mr. Chairman, to offer proposals for future and long term action in the energy field. I think that one of these actions should be oriented towards a greater efficiency in the use of energy. One figure, just to illustrate. If you look at economically recoverable resources at present, and go through extraction, conversion, transport, and utilization, you would then note that just 15–20%—roughly—of the energy content contained in energy resources of the world are efficiently used. Studies undertaken in various countries now indicate that we could increase the efficiency of energy use in extraction, conversion, transformation, and so forth by 50% or even 60%, involving, however, a certain change of the way of life of our society. This will take time. But should we succeed in making governments aware of this potential for saving, we would make a very important contribution to solving any long term energy problem.

LEWIS: I should like to say that I very much appreciate M. Gibrat's courtesy in discussing the differences that exist between our opinions and those differences remain. However, I am speaking on something on which we agree; that is the very important, urgent, immediate step to fight against fallacies in the world; particularly against those fallacies which produce fear. There is a fallacy abroad—a widespread idea that after exposure to quite low levels of radiation a person—especially a young person—is likely to die of leukemia. Table 1 shows the latest and best information of the results of irradiation from the A-bomb survivors (Hiroshima and Nagasaki) and the reference is given there as to where the information is published.

TABLE 1. Mortality Among A-Bomb Survivors, 1950–70 (Data from S. Jablon and H. Kato, TR-10-71, Hiroshima and Nagasaki ages at time of bomb 0 to 19 years, in 1970 25 to 44 years)

Assigned T 65 dose	Persons		1950 to 1970 deaths from All causes	Leukemia
All "known"	32 100	observed	1147	46
		expected	1106.1	14.1
> 100 rad	2441	observed	128	24
		expected	91.6	1.2
10–99 rad	7085	observed	224	11
		expected	236.2	3.1
0–9 rad	22 574	observed	795	11
		expected	778	9.9

Expected deaths based on Japanese National Statistics 1960 for same age and sex distributions

You will notice that this refers to those who were irradiated at the ages of between zero and 19 years. They have been followed until 1970—that is 25 years—when their range of ages were from 25 to 44. From the 32 100 people irradiated there were observed in those 25 years 1147 deaths. The expected deaths on the Japanese

National Statistics for 1960, for the same age and sex distributions, would have been 1106.1. Not a very great difference but a very significant difference in the case of leukemia. For there were 46 deaths attributed to leukemia, whereas in the normal population there would have been 14.1 expected. Now let us see how this breaks down. The same 32 100 total broken down below, there were 2441 assessed as radiation doses of greater than 100 rads—that is a fairly considerable dose. Of those, there were 24 leukemia cases whereas the expectation for such a small number would have been 1.2. Now we come to the next level of radiation, the range from 10 rads to 99 rads. There were 7085 persons and, rather remarkably, the observed deaths were just rather less than the national expectation: 224 instead of 236. But again, there was an excess from leukemia. Then we come to a very large number of people in the range of 0 to 9 rads: 22 574. There is no significant difference between the leukemia deaths in the unexposed population and those that were exposed in this bomb explosion. Table 2 shows another report from the same people, from the Atomic Bomb Casualty

TABLE 2. Observed and Expected Deaths from Cancer in Ten Years
(Seymour Jablon and Hiroo Kato, *The Lancet*, November 14, 1970)

			Cancer deaths under 10 years		
				Expected	
Maternal radiation dose (rad)	No. of Children	Maternal person–rad	Observed	At Japanese national rates	Extra at 572 per million person–rad
>1	551	—	0	0.32	—
1–39	467	5495	0	0.27	3.1
40–299	215	22 699	1	0.12	13.0
300–499	17	6739	0	0.01	3.9
500+	16	29 557	0	0.01	16.9
Unknown	26	—	0	0.02	—
Total	1292	—	1	0.75	36.9

Commission. It concerns something that is controversial in biological circles, in human biology, because the general expectation that people had grown to expect, and that Jablon and Kato were using, was that from a total of 1292 children who were exposed before birth, exposed *in utero*, to the atomic bombs—because they know the timing of that very well—and these were live births, it was expected that there might have been 36.9 childhood cancer deaths; instead what was observed was one. And that one was a girl whose mother had received 170 rads and that is all, up to the age of 10. And there was no leukemia case. There was one leukemia case at the age of 18 (not shown in the table). The dose in that case for the mother was estimated at 1 rad, so it was not expected that there was any connection because the basis for that expectation of 36.9 deaths was quite a simple calculation as follows:

It is necessary to discuss three factors: the natural risk c_i (unrelated to pre-natal X-ray), the fraction of pregnancies k_i selected for X-ray, and the apparent radiation factor r_i. For each, the subscript i denotes that it relates to an identified subgroup.

By definition
$$r_i = \frac{d_{iu}}{d_{io}} \cdot \frac{p_{io}}{p_{iu}}$$

where d_{iu} is the number of childhood cancer (or leukemia) deaths in the groups of those irradiated *in utero*, d_{io} is the number of such deaths of those without *in utero* X-ray, p_{iu} is the number in the group or control group i receiving *in utero* X-ray, and p_{io} is the corresponding number without X-ray.

It follows also from the definitions that k_i the fraction X-rayed

$$k_i = p_{iu}/(p_{io} + p_{iu})$$

and the natural risk without X-ray c_i

$$= d_{io}/p_{io}\,.$$

Table 3 shows that the statistics on which that expectation of 36.9 were based are not valid. This does not prove that there is no relation but it shows that there is not necessarily any relation between the obstetrical X-rays and the childhood cancer deaths. What we have here is that there were 1141 childhood cancer deaths

TABLE 3. Childhood Cancer—Oxford Survey Interpreted for Zero Radiation Effect

Birth rank	d_{iu}	d_{io}	p_{iu}	p_{io}	r_i	$1000\, c_i$	k_i	$f_i\%$
First	275	2472	275 364	2 478 276	1.00	0.9974	0.10	36.0
Second and later	279	3228	367 032	4 239 658	1.00	0 .7614	0.07967	60.226
High risk	460	685	45 989	68 501	1.00	10.0	0.4017	1.4968
Standard twins	37	41	77 228	84 016	1.00	0.4846	0.47895	2.1080
High risk twins	75	8	7637	849	1.00	9.764	0.90	0.1109
Mongols	15	74	750	3700	1.00	20.0	0.1685	0.0582
A11	1141	6508	774 000	6 875 000	1.5573	0.9466	0.10131	100.0

of those irradiated and there were 6508 childhood cancer deaths of those not irradiated. But, nevertheless, because P, the population numbers were different, it appears that on the overall total (column 6) the individual apparent radiation effect was a factor of 1.55. However, if you will do the arithmetic on the numbers that are above, you will find that the totals are all correct and that this can be made up out of the groups that are shown there—first birth, second, and later births, high natural risk for individuals, standard twins, high risk twins, and those with mongolism. In all those cases with no radiation effect, in fact r_i equal 1.0, you find that you can add them up and you can get this final result. In other words, this is a trick of statistics that is just demonstrating that the conclusion was invalid. It is very sad. People have worked for years and years trying to establish this relation between the irradiation of the fetus and some childhood cancer effect. But that, I am afraid, shows that it is all invalid.

STEWART: I should like to address some remarks which I hope are relevant to the present discussion but which are directed to the economists who were talking to us yesterday morning. I have been sitting here in amazement because all day yesterday—and particularly in the case of Professor Dubos' intervention just before the break—we heard an attack on what seems to me to be the very core of the discipline of economics, with no response at all from the economists. In Professor Dubos' talk we heard energy discussed as though it were not part of economics. We heard talks about energy savings calculations and of efficiency in energy use which were unrelated to costs. I am a fluid dynamist, not an economist, but it seems to me that the very basis of economics demands that when you do a calculation you must calculate commensurate things. You must insist that the various inputs to your cost calculation be commensurate, and the various inputs to your benefit calculation be commensurate. Otherwise no efficiency calculation is possible. Yet here we have heard such a straightforward thing as energy being treated as though it were not commensurate with money. This seems to me to be an attack on the very core of economics, and yet we have heard nothing from the economists. Perhaps this is because of the point raised by Harrison Brown—that we are subject to changes that are too fast for the normal course of economic adjustment, and perhaps too fast for the adjustment of the thinking of economists.

Perhaps a relevant question which can be a source of these difficulties lies within the discipline of my friend Professor Benoit Mandelbrot, sitting next to me, who is probably the world's leading expert on contagious distributions. It appears to me that the economists are not fully aware of the possibilities and dangers which may arise if nonrenewable resources such as oil and mineral ores occur in such contagious distributions—and indeed it seems that the evidence supports such distributions. If so there is a considerable probability that we may quite suddenly come to the end of some readily available, comparatively cheap resources: too suddenly for our technology and our economics to adjust to the use of much more expensive less concentrated ores, for example. If this happens we must expect to encounter in the future other situations where real shortages will develop very quickly. As with energy now, we will then no longer have commensurability with respect to these materials which have suddenly become scarce. I believe that this loss of commensurability attacks the very core of economics as it is presently practiced.

BEN MENA: J'adopterai la même technique que Monsieur le Professeur Dubos.

Monsieur le Président, une question a tout à l'heure été posée par Monsieur Brown, concernant les pays en voie de développement et plus exactement les ressources énergétiques pour ces pays en voie de développement. Je peux déclarer que le problème de prévision pour ces pays me semble être beaucoup plus facile à résoudre que les prévisions pour les pays développés et je vais essayer de dire pourquoi. Dans la mesure où pour ces pays, une croissance est absolument souhaitée, indispensable et que cette croissance va se faire suivant un modèle qui est déjà connu par les pays développés, il n'y a pas d'aventure vers l'inconnu. S'il y en a une, elle a une probabilité beaucoup plus faible. Par ailleurs, il est absolument admis que la croissance de ces pays-là (les économistes pourront certainement étayer cette thèse), sera plus forte que la croissance démographique. Par conséquent, je dois avouer que je ne suis pas absolument d'accord avec ce qui a été avancé par Monsieur Destival sur les valeurs de la consommation d'énergie entre 1970 et après l'an 2000.

Comme l'a rappelé tout à l'heure Monsieur Gibrat dans son rapport, Monsieur Destival prévoyait un facteur 2, ce me semble un facteur faible et j'ajoute encore: si nous devons tenir compte, comme je l'ai dit tout à l'heure, du progrès économique que ces pays en voie de développement doivent accomplir, du niveau de vie souhaité qui doit augmenter à son tour, il me semble que le facteur des besoins en énergie global, mondial entre 1970 et l'an 2000 serait plutôt égal à un facteur 4. Telle est ma première observation.

Deuxième observation: de crois qu'il faut aussi insister sur un aspect qui a déjà été soulevé: l'aspect de l'économie, que l'on doit rechercher; peut-être une approche nouvelle dans la recherche de la rentabilité doit-elle être effectuée pour que la demande des combustibles fossiles (et je parle principalement des combustibles fossiles actuellement) n'aille pas en grandissant, comme nous l'avons tous remarqué, et ceci dans l'intérêt, je pense, de toute l'humanité.

DOSTROVSKY: I wanted to refer to the point raised by Harrison Brown and other speakers. We did, indeed, ignore short term problems, not because we thought that they did not exist but for two reasons. First of all because of the terms of reference, and, secondly, because on the short term problems there is really very little one can do in the way of new technology. You are all aware of the time constant for various technological developments. Things that were not done 30 years ago cannot be done overnight. In fact we are suffering now from the years of neglect. What we can do now will only have its effects seen 25 or 30 years from now. I think this is the reason why all of us are addressing ourselves to the year 2000 because that is probably the earliest time that any major conclusion or any major change or major technological developments will have an effect. So the problem that you raised, Mr. Brown, is a very serious one. I myself share your pessimism and your worry and anxiety about the near future. However, as I say, there is not much one can do immediately in the sense of substitutions. Here I want to really emphasize that in a sense, in my opinion the situation of today shows the failure of relying on the classical market place mechanism for automatic adjustment. After all, what happened? The policies on energy were dictated essentially by the oil companies; in the terms of their own microsystem where they wanted to maximize their profits, presumably. That is exactly the situation today. In a session on economics which we had, large emphasis was put on the good mechanism of the market-place so to speak, of whether the market-place will decide or will bring about substitutions. Here we have a clear case where this did not work. If we are to develop substitutions, we shall have to have some more concerted action and more even government-controlled action to make sure that these come in time. Now again the time scale for all this is long. To my mind the greatest immediate benefit could come not so much in the deployment of new energy sources but in activation of various other energy conserving methods, to solve which may require simple technologies. The question really comes down to maximizing effort and proper location of our efforts. How much effort should we make working towards further sources and how much effort at the same time should be devoted to reduce the gap, the same gap that you are mentioning, by other actions—some of which were mentioned by Professor Dubos. Even if we accept the minimal growth rate of Mr. Destival—and I personally admit I am closer to Mr. Destival's views than to the more maximalistic views Mr. Lewis has been propounding—it still represents a tremendous effort to provide these energies. After all, people cannot use more energy than is available. That is just impossible. Therefore the real thing to do is to find out what is the maximum rate of deployment of new energy resources. How many new reactors can we build a year, for example, even if you accept Destival's view you still have to build reactors at the rate of ten a year or something of that sort? Which means that at any one moment we should be having 700 reactors under construction. I am not aware that this is happening or likely to happen in the near future. I think that some of these figures we are talking about are just not attainable because of the effort involved. Because of that, I think that much greater emphasis should be put to changing our way of life in such a way that it will not require this effort, and therefore the gap between what we would like to have and what is achievable will be smaller.

HORVAT: The economists have been challenged and let me try to meet at least partially this challenge. If I understood correctly, two points have been made. First we did not take into account the cost of energy, and, secondly, that we did not take into account the distribution of energy. I made a quick and rough calculation about the development of the cost of energy in the last 100 years. I was working from my memory, so I might be wrong, but I believe the order of magnitude will be about correct. It turned out that in the last 100 years the cost of producing one unit of energy has been reduced between 10 and 20 times per unit of labor because that is the only real cost; money does not really matter. Now the point is, what are the prospects? From the report we heard this morning, if in the next 50 years we have a breeder developed, then per unit of fuel we may expect between 50 and 70 times more energy than today. So I think that one is bound to conclude that the trend is likely to continue, the same trend from the last century is likely to be extrapolated in the next century. Since no one has detected any discontinuity in the consumption of energy, we are probably correct in assuming that the cost of energy will not be going up, or at least will be behaving the same way as in the last 100 years—which is certainly not alarming. About the distribution of the energy sources: as far as the economy is concerned, all the irregularities in the distribution are corrected by world trade. If by political power the free movement of goods and resources is prevented beyond the national borders; if again by political power monopolies are established and so prices soar up; and also if, due to the political structure, the domestic regimes are inefficient and are unable to organize production so that it meets the consumption of their people in the poor countries and the political regimes in the developed countries are

unwilling to provide the export outlets for poor countries to be able to buy their imports (which by the way is just the case in Europe today, where you cannot import meat any more because the European governments, in spite of all G.A.A.T. agreements and everything else, have decided to prevent any import of meat any more)—if because of these political factors difficulties occur it is not up to economists to solve them. Professionally it is the political scientists who have to be asked for the proper solution.

KELLOGG: In view of the short time and the many other people who wish to speak I shall try to abide by my five-minute limitation, particularly in view of the fact that M. Gibrat's summary was really very excellent in general, and as it concerned the subject I was assigned, namely the effect of future energy generation on the climate, I thought he covered it rather well. There are just a few things that I would like to emphasize. Even if there were no climate change due to mankind activities, there would undoubtedly be climate change anyway. This, I think, is a fact which we must recognize, and the world must be prepared for the kind of things that have been happening lately: the drought in the Sahel of Africa, for example; changes in the monsoon circulation; the extreme drought in the summer of 1972 in the Soviet Union, which, by the way, is a good example of how climate change in one place can effect the entire balance of trade of the whole world. In 1972 wheat prices everywhere went up as a result of drought in one place. The whole economy of the world is tied together now in a way in which it has never been before. Furthermore, it is probably going to be even more interactive in the future than it is now.

The fact that man is entering into the equation that governs climate change is, in my opinion, almost a certainty. If he continues to expand his capacity to produce energy (and it does seem to be the consensus that this will happen), the result will be a global warming, both due to the carbon dioxide he puts into the atmosphere from burning of fossil fuel and, on a somewhat longer time scale, due to the direct addition of heat. This has been pointed out before—I am not the first person to make this point. In general, a warming would seem to be advantageous for the marginal areas at high latitudes, particularly in the northern hemisphere where most of us live. I made the point that a 1° increase in the temperature on the average results in 10 days more growing time between frosts. We may be talking about several degrees of increase at high latitudes in the next 50 years if man's activities are to take hold. This would seem to be a good thing, on the whole, for the northern areas. However, we know from past experience of climate change that every climate change is accompanied by diverse effects in many places. I shall not go into the details, but this is due to the fact that the atmosphere has standing waves, and the climate change results in a movement of these standing waves so that, whereas some regions will warm up, it is quite possible that in the face of a global warming other places will become colder. Certainly the precipitation patterns will change all over the world due to such a large change in the circulation. Therefore this growing interdependence of the food economy of the world means that a climate change anywhere will have many kinds of repercussions that will go through the whole system. We are going to have to readjust no matter what climate changes we have. As the meteorologists, the oceanographers, and the climatologists refine our models of the climate system we may in the future be able to draw a clearer picture than we can now of the patterns of future climate. But one thing I think we can guarantee is that there will have to be readjustments, and complex readjustments, in the economy of the world. There is one other point which I think was not made entirely clear by M. Gibrat. We very often hear of the possibility of sea-level rising as a result of a general warming because of the thought that a warmer temperature would result in the melting of the great ice sheets of Greenland and the Antarctic. We now believe, as a result of looking at the last glaciation that ended some 10 000 years ago and also based on some rather simple thoughts about the fact that if you warm the atmosphere it can contain more water vapor, and then more snow will fall on these icecaps, which are generally below freezing. So both theory and experience suggest that instead of a melting of these ice sheets, quite the opposite will probably happen as a result of a few degrees of warming. They will probably get larger, and this would result in a small lowering instead of a rise of the sea-level. I think this is an important concept to keep in mind when you hear that mankind is doomed because all our coastal cities will go under water. This does not seem to be on the cards as I see it.

CHENERY: Well, since economists are being challenged, I shall try to respond. Unfortunately, I do not entirely agree with Mr. Horvat, who sees in the long run no particular problem. I think the problem is precisely in the next 30 or 40 years in which we need to have a transition in sources of energy and in which there are a number of discontinuities. Perhaps we have given the impression of being optimists—that the price system solves most problems. M. Malinvaud pointed out in his summary yesterday the number of problems the price system as practiced does not solve. One in particular is that it does not signal very well future prices. Here, I think, it is one of our problems now that energy has been underpriced for the last 18 or 20 years in terms of the stimulus that should have been provided to the development of new technologies and to economy in use. The various wastes of energy in modern building would not have occurred if energy had been priced higher in the last 10 or 20 years. We cannot rely on the price system to give that signal. Governments really have to intervene in looking ahead in the way that markets do not.

I think that we should recognize that in a way the Arabs have done us a favor by correcting the price of energy, making it somewhat closer to what its future scarcity value is and stimulating both economy in use and the more rapid development of technology or shift to other sources which will need to take place. But, as I understand it, the problem will be much more acute in the next 30 or 40 years than in the longer run. I think the other failure of the market system is more difficult to remedy, namely that it does not provide a

very good distribution of income either among people or among countries. Here it is much harder to see a solution. The energy effects on the developing countries which have been pointed out are extremely acute. In solving one problem by raising the price of oil, we have worsened the effect of the low income—in this case the actual purchasing power of India and other poor countries, so that they have a serious payments problem. India has to pay nearly $1 billion more for its imported energy, which augments its food problem. I really see no alternative solution to this kind of problem. I think the world has to recognize it. It would be quite easy for the O.P.E.C. countries, which have increased their earnings from the sale of oil by about $1000 billion per year, to solve this problem by a transfer of the resources to the poor. I would not be particularly optimistic that they were going to do that. I should think—although this gets us away from the use of energy to the world economy—we should not look for a solution of cutting as we do in the advanced countries because material progress is essential in the poorer countries.

BLACKSHEAR: I am from the State of Minnesota, U.S.A., where we have an energy shortage and an agricultural productivity that has led to a group at the University of Minnesota to look at a technology that might be of interest to the developing nations. The amount of energy that is contained in our grain crop is almost exactly equal to the total energy of the budget of the State of Minnesota, 10^{15} Btu per year. The amount of energy that goes into the State's agriculture is about 6% of that, including the energy for making fertilizers. There are currently processes available in the developing world for making ammonia out of coal. These processes would apply directly to making ammonia out of crop residues. The amount of residues that accompany the grain production that I discussed contains energy which is a little bit greater than the grain. To maintain soil tilth, it is suggested by our soil specialists that we leave a part of this organic residue in the ground. However, the amount of fixed nitrogen that can be obtained by processing the residues through gassification and then nitrogen fixation would let it be possible to make enough nitrogen for 100 kg per hectare with only 10% of that energy in the grain, hence in the residue. This would leave a residue of energy for synthesizing methanol if we have to use existing internal combustion engines in the tractors. Or if the Philips Company and Ford and others who are working on the sterling engine are successful, it should be possible to have even more energy by burning crop residues directly in the sterling-driven tractors. I think, along with Professor Brown and others, that the chief focus in this crisis of humanity ought to be in the developing nations. I have certainly appreciated this meeting as a place of focusing emphasis, which I hope will be of use in directing our engineers in developing new technologies.

DI TELLA: When we speak of a plan for action we should keep in mind the question of political problems and conflicts. For example, the present energy crisis in Europe and in the developed world is not really caused by a physical scarcity of oil. It is due to a political phenomenon. Most probably the type of problems we are going to face in the 20 or 30 years are of this type, rather than actual scarcity of resources. We might discuss whether in the very long run there is going to be a physically imposed crisis of lack of raw materials. But the situation which is just around the corner is one of increased world conflict due to pressures from various countries or regions in the world for access to resources using political action. We should give more attention to this; in a sense preparing for world planning. One of the elements of world planning should be world prices.

FORRESTER: There is an underlying fundamental issue that has not been raised in this discussion of energy. Everyone is assuming that the condition of mankind will be improved if we produce more energy. But we should ask whether or not we want to solve the energy problem. More energy can create new difficulties. Our social systems can transfer pressures from one part of the system to the other. If we relieve the symptoms in one part of a system, other symptoms will appear elsewhere unless we have mastered the underlying cause of pressure. Most of our social difficulties are being generated by rising population. As population comes against a sequence of limits, pressures appear in one place after another. Most concern is now being expressed about the physical limits—land, food, energy, resources. But there are another set of very important limits. These are the social limits that manifest themselves in aircraft hijackings, drug addiction, mental illness, revolutions, and the ultimate one of international atomic war. Removing a physical limit takes emphasis off the question of rising population and therefore encourages higher population density. Higher population density increases social stresses by increasing social complexity and interpersonal conflict. So, solution to the physical limits will be seen in the long run as a process of shifting from physical stress to social stress. It will be a poor bargain because we know so little about coping with social stress. An energy shortage should not be taken as a technical challenge to be overcome but as a warning and as an aid to slowing growth before we reach the point of social breakdown.

DATTA: It is significant to note that people of the developed countries, representing 25% of the world population, use 85% of the world energy. In the world plan of actions, such a discrepancy is highly untenable, and planning should tend to reduce this gross inequality. In the developing countries the pattern of use of energy is such that there are three groups of areas, e.g. (a) rural areas wherein a good number of people live, (b) small towns, and (c) large metropolitan towns and industrial areas. The energy needs of these groups are entirely different. In the case of India, the (rural areas) villages with a population of less than 1000 in each cover the major part of India's population (in some 466 600 villages the population is nearly 250 million). Meagre energy needs in this group are for cooking, lighting, pumping of irrigation water, portable water, drying, and limited social and cultural activities. The daily average consumption of energy is between 150

to 250 kWh per village. Cowdung, firewood, and kerosene are the mainstay as sources of energy. In the group of small towns (urban situation) in India with populations between 1000 and 10 000 (constituting 200 million), the consumption pattern of energy is (i) agriculture, 35%; (ii) industrial, 30%; (iii) transport, 5%; (iv) domestic, 10%; (v) others, 20%; the average daily consumption per town being 1000 to 10 000 kWh. In metropolitan and industrial towns of India, in each of which there is a population of more than 100 000, involving a few square kilometers or more, the requirement of energy is mostly for (i) industries, 70%; (ii) transport, 3%; (iii) commercial activities, 8%; (iv) household, etc., 6%; (v) others, 13%. In any plan of actions for future mankind, these realities of the developing countries must find a place. The overall picture of the energy consumption pattern in India is such that of the total consumption of energy in 1970–1 (409 million tons of coal replacement), 45% of this was from noncommercial sources, e.g. dung, firewood, and waste; in earlier years this percent value was higher; it is expected that this value will come down to 30% by 1978–9; coal, oil, natural gas, hydro and nuclear constitute the commercial forms of energy. There are terrible limitations of the reserves of oil, natural gas, and hydropower; nuclear power in India has recently started taking root. Coal, whose proved reserve in India is 26 000 million tons (gross = 83 000 million tons) appear to be the mainstay for the commercial source of energy at least for a few hundred years at the present annual rate of consumption of 74 million tons (which is being doubled in a few years' time). With the internal production of crudes at 7 million tons annually, and requirement of 24 million tons per year, the foreign exchange bill for import of 17 million tons of crude per year will cost the Indian exchequer Rs.12 000 million (as against Rs.2000 million earlier) (1.7 rupees = 1 FF). Of the projected commercial power requirement in India corresponding to a capacity of 30 MkW by 1979, 60% of this power will be by thermal and about 40% by hydro, and a little by nuclear; by the year 2000, with the per capita consumption raised to 1000 kWh, the required power capacity in the commercial sector has to be raised to 200 MkW; for the entire energy requirement one has, therefore, to look to the alternate sources of energy like solar, wind, tidal, geothermal, fuel cells, and magnetohydro dynamics. While the limit of hydro power (at 60% load factor) is estimated at 41 MkW in India, the tidal and geothermal power capacity will be 1000 MkW each; solar energy, although diffuse, is available for a longer period of the year in India and also in many other developing countries. Assessment has to be made for both commercial and these alternate sources of energy in the developing countries. In framing the global energy model in the plan of actions for future mankind, these pertinent parameters of the developing countries should be effectively fed into the model to make accurate forecasts.

RANDERS: Thank you very much, Mr. Datta. We now have two suggestions of how to solve the problems of the advanced world. Most proposals seem to indicate that we should use less energy per head in the future in order to overcome the difficulty that we can see meeting us in the future; we must reduce the use of energy. On the other hand, we have the request from the technologists that we should produce more energy, better reactors, solar energy, fusion, and so on. That is the opposite request.

The third possibility which Dr. Forrester mentioned was that maybe we would prefer to live with the physical limitations of energy instead of meeting the social limitations that would destroy our society for other reasons which might be even more unpleasant. It might be easier to be forced by physical pressures to live a simple life in our society.

Now as regards a solution to the developing countries, we have not had any real good suggestion during our entire meeting. Obviously we have understood that the developing countries must have an increase. While this is doubtful for the advanced nations, there is no question but that there be a doubling and redoubling for the developing nations.

It has been pointed out that this really means more energy than we can provide in the next 30–50 years. So here we have not really had a positive suggestion for the solution because nobody has suggested that the tapering off in the developing countries yet, while this has been done for the advanced countries. I just wanted to make this observation.

PEYCHES: Un sujet me tient à coeur: le rôle de l'énergie solaire pour les pays en voie de développement.

Plusieurs personnes se sont étonnées que les problèmes soulevés par les besoins en énergie aient été surtout développés dans l'optique des pays nantis. D'autre part, l'énergie solaire n'est intervenue que d'une manière allusive et le seul exposé qui lui ait été consacré en Commission ne concernait que le cas d'un pays hautement industrialisé: le Japon. Je voudrais rectifier tout d'abord deux affirmations entendues au cours des débats.

— L'énergie solaire est pour le prochain siècle. Rien ne justifie cette affirmation car il n'y a pas de phénomène nouveau, pressenti aujourd'hui, qui puisse modifier radicalement la tare de l'énergie solaire: sa faible densité énergétique à la surface de la Terre. Dès qu'on l'accepte, toutes les technologies de captage et de conversion sont disponibles dès maintenant et ne demandent qu'à être affinées et surtout généralisées.

— L'énergie solaire demande (*pour un captage en puissance*) des surfaces prohibitives. Un chiffre a été cité: 6000 hectares pour une centrale solaire de 1 gigawatt. Je rappellerai que la retenue du barrage d'Assouan, d'une puissance comparable, couvre 500 000 hectares. Le barrage fournit 2 kWh/m²/an, alors que sa retenue reçoit du soleil 2500 kWh/m²/an. Même avec le rendement de la photosynthèse à 2‰, la culture d'algues sur cette surface, mises en fermentation pour alimenter une centrale thermique produirait davantage. D'autre part, il faut aussi prendre en compte la surface à neutraliser—pour des

questions évidentes de sécurité—autour d'une grande centrale nucléaire. Je crois qu'un rayo 4 km n'est pas superflu. Donc l'argument *surface n'est pas décisif.*

Je conviens pourtant que l'utilisation de l'énergie solaire en centrale de puissance n'est pas dans sa voca naturelle; par contre l'usage *dispersé*, tel qu'il apparait possible dans les pays en voie de développemen bénéficient en général d'un excellent ensoleillement, parait pouvoir constituer une aide majeure app(aux populations, et il est regrettable que cet aspect n'ait pas été mieux examiné au cours de cette confér(

Cette remarque ne concerne qu'un aspect d'un sujet bien trop vaste.

CAPRIOGLIO: I would like to address myself first of all to the economists, since this is becoming fash able today after their request to give them expert advice. I am not so sure they are going to be satisfied b the expert advice we are giving them. Of course, it is somewhat naive to expect expert advice in a diffi and new field. It takes time to create a scientific truth and for experts to agree on it. In fact, it takes tim create anything and do anything for mankind. This is the first point I would like to make. Among limits of growth that we can talk about there is one we have presumably already touched and this is prob why we are so concerned about so many other things. This is the limit connected with the time constar mankind and this time constant is in time linked to the succession of generations. It takes years to buil anything, it takes years to build up our beliefs, it takes years to change one's cultural background; in fa takes generations to change cultural backgrounds—this is the time constant that we are faced with.

If we keep the rate of development of mankind within reasonable limits, its capacity for adjustme very large indeed. And "reasonable" means "compatible with the capacity of each generation to adju The real problem is that, during these last years, we have been touching the limit of acceleration th generation is ready to accept and cope with. This is certainly much more true of social and cultural is than of physical or material questions.

The difficulties that Dr. Forrester was seeing I think are visible to anybody, but I do not think they are to growth as such. They are most likely due to the fast acceleration of growth that has taken place du the last 20 or 30 years, and this has touched on the very fundamental problem that mankind is always cap of change, but on the condition that enough time is available. Any individual cannot change his opinions his behavior, or his habits, too many times in his life.

Having said that, I am not going to try and convince anybody about any technical matter. I am sin going to present a few beliefs I happen to have, knowing that each of them can be challenged.

The first one is that the absolute limit of growth is very far away, more than a few generations av The second one concerns energy. What in fact we need is not energy, it is negative entropy. And this is v electricity and hydrogen are so important and are likely to sweep the energy market: they are rich in nega entropy. The third belief is that, at the primary sources of energy, there is hardly any problem in 50 or years or more even. But, because of the long time-constants involved, we are likely to have problem: short term. As far as transport and utilization of these primary sources is concerned, the situation is, on contrary, quite worrying both at short and at long term. The natural consequence ought to be that resea should be concentrated on transport and utilization of energy rather than on making primary sources av able. Unfortunately the contrary is true, and this is why I am pressing for an intensive development of hyd gen production and utilization.

Finally, I believe that we should take the habit of thinking one generation ahead (30 years or so) and p one generation ahead. It is not going to be easy, but it has to be done if sensible decisions have to be tak

RANDERS: Thank you. I want to point out that I have speakers who will take up the rest of the tim the discussion here. Of course if something very urgent should come up we will try to arrange it because it is, we might not even have time for everybody on the list. It may not be necessary to have a popular vo we may manage to do it in the time allotted; I will try. Now if everyone will cooperate, Mr. Oyawoye will able to speak.

OYAWOYE: When I was invited to participate at this conference I accepted with a rather diffe understanding of what it was all about. I am not saying this as a way of saying that I was disappointed— from it—it is just that my understanding has changed since. I thought that the conference was concern from a global point of view about the whole of humanity and the dwindling resources of the earth. I th that, generally, human beings are supposed to look after their own immediate interests with more conc than those of others. In this respect I should say that I was greatly impressed by the concern that was sho by a large number of people from the developed countries about development in the poor nations, bu must say that I was disappointed in some sense by the fact that certain emphasis is now being placed on problem of that part of the world which consists only of overdeveloped and developed people. We sometir forget that the world contains also developing people as well as very underdeveloped people. I think t when we talk about the resources of the earth we talk in terms of food, fresh air, metals, and energy; a these are things which are essential to good life and good living. I think that the problem which appears me to have been discussed so far is how do we, that is the affluent people, continue to maintain the type life that we are having now without having to go back or restrain growth.

I am not saying that this is what everybody has said, but I think it represents the average of the gene discussion that has gone on. The tone in the energy report appears to be—don't worry, Let's go on as

have been doing. By the time we develop hydrogen and nuclear energy and so on, everything will be O.K. They missed the point of the conference. I think that the real problem is—if viewed from the total world concept—not really how do we bring in to use other types of energy sources in the 30 years. Assuming that the world consists of every people—poor, average, rich, and very rich, and with a limited amount of food, fresh air, metals, and sources of energy, the problem is how to go about sharing these among the people of the world to maintain a certain amount of equity. As far as shortage is concerned, I think at the moment there is in a way of thinking no problem for underdeveloped countries. As we say in my own country, if a person is already flat on the ground he cannot fall very much further. The total amount of energy we underdeveloped people consume at the moment is so insignificant that even if we raise it by 10% the increased amount would not come to what we or anyone could worry about. I think it would have been fairer at this discussion to put more emphasis on the ethical question: How should the rich nations go about maintaining their high living standard without putting so much pressure on the earth's resources, raising the prices so much that the people who are way down have no chance of coming up at all? I think there is more of a problem there for humanity as a whole than the questions on which I think emphasis is being placed. I think it is fair to say that if less pressure was put on, say, world resource of petroleum by the developed countries, the price would automatically adjust itself to a level which would not cause the type of problem which was being faced by developing countries at the moment. The question I kept on asking myself was whether it was appropriate —but I am not insisting that it was appropriate—for people to say that it is equitable; for one to insist, for example, on lighting a room with ten times the amount of light that is actually required to see comfortably, just to make it more pleasurable to look at. But you see this is looked at from a different background, and perhaps from a little more selfish point of view. But I say this because I like that way of thinking and it was responsible for my opening remark. I shall not take more of your time, Mr. Chairman, but I think that one would be unfair to himself not to underline the essential points which I have tried to make, which, in short, are these: I think that the problem for developing countries is a question of whether food, metals, energy, and fresh air will continue to be available at prices which will make a start with their development possible. I say that if the developed countries continue to put such high pressure on these materials by consuming at an accelerating rate as they have been doing, the price will go up and the shortage will crush the underdeveloped countries.

MALINVAUD: Je serai très bref, Monsieur le Président. Je voudrais simplement signaler que, s'adressant aux économistes, certains de nos collègues commettent une fois de plus des malentendus. Je voudrais en prendre deux exemples: le premier concerne l'incertitude de la croissance future, incertitude qui peut même prendre une forme extrême, telle qu'elle est illustrée par les lois de mon ami Mandelbrot. A écouter ce qui a été dit hier après-midi et ce matin, j'avais le sentiment que les économistes avaient insisté sur cette incertitude plus que les autres. Nous n'avons pas cité de chiffres pour le rythme de la croissance, parce qu'il aurait fallu à chaque fois les accompagner de marges d'incertitude. Il me semble que les spécialistes des sciences physiques ont été beaucoup moins prudents sous ce rapport. On commet une erreur si l'on imagine, par exemple, prévoir précisement la consommation d'énergie en 1990. Toute notre stratégie d'action doit donc tenir compte de ces incertitudes, comme j'avais essayé de l'expliquer et comme le Professeur Meade avait essayé de l'expliquer lui-même.

Le deuxième point concerne le rôle que joueraient les institutions actuelles pour assurer une progression régulière et continue dans l'utilisation des ressources. On nous a accusés de croire que tout s'arrangerait bien, sans que soient fondamentalement changés les modes de décision actuels. Là encore, il s'agit d'un malentendu. Sans aucune modestie, je vais vous renvoyer à mon article dans l'ouvrage que vous avez à votre disposition. Aux pages 45 et 46, j'ai traité du contrôle de la croissance économique globale, en accordant un certain soin au choix des mots. Puisque ce texte a été discuté dans notre groupe et puisqu'il n'y a pas eu d'objections à son sujet, il reçoit l'adhésion de la plupart de mes collègues. Il y est écrit que l'on n'a absolument aucune garantie, que le système des prix jouera correctement pour fixer le rythme de la croissance économique et celui de l'utilisation des ressources.

Cela a été écrit avant cette réunion. Il ne faudrait donc pas attribuer ici une attitude que nous n'avons pas.

Je voudrais, si vous le permettez, terminer par une note un peu émotionnelle qui m'est personnelle. On nous reproche de croire que les institutions actuelles du monde sont satisfaisantes. En fait, la plupart d'entre nous sont économistes parce qu'ils sont convaincus du contraire et parce qu'ils ont voulu travailler pour améliorer les modes de décision qui s'appliquent dans nos organisations sociales.

DALCQ: Je suis un peu gêné de prendre la parole parce que, contrairement à ce que font en général les autres orateurs, je ne puis invoquer aucune spécialisation d'aucune sorte: je ne suis spécialiste de rien du tout.

J'ai été nourri de "principes biologiques" par mon père qui a créé labranche belge de l'Institut de la Vie. Cela ne m'a pas empêché de prendre un doctorat en chimie et de m'intéresser aux sciences économiques, d'entrer dans l'industrie et puis finalement l'industrie m'a demandé, il y a 4 ans de m'occuper de protection de l'environnement. Ainsi la boucle se referme puisqu'il s'agit de la protection de la qualité de la vie et de la vie ellemême.

Si je prends la parole, c'est simplement parce que j'ai été encouragé par l'appel vibrant à la pluri-disciplinarité par lequel Monsieur Gibrat a terminé son exposé magistralement clair et simple. Il nous a dit que nous pouvions attendre beaucoup de puissance des surgénérateurs et H.T.R. Il nous a dit aussi qu'il y avait

de même un grand danger: celui du plutonium, qui pouvait tomber dans les mains d'irresponsables ou être utilisé à des fins auxquelles il n'est pas destiné. On nous a dit aussi que les besoins en énergie allaient s'accroître considérablement. Monsieur Destival pense qu'ils vont doubler, d'autres collègues des pays en développement pensent qu'ils vont quadrupler, cela n'est pas mon problème. Je n'ai aucune compétence pour discuter de ces choses, mais ils vont augmenter considérablement. Il faut donc, comme on l'a souligné, que dans les 25 ou 30 années qui viennent, on dispose de ces sources d'énergie et il faudrait qu'elles soient le moins polluantes possible et qu'elles ne soient pas accompagnées de la présence de ces produits très dangereux, même si l'on croit pouvoir les maîtriser du point de vue sécurité à 99 ou à 99,9%.

Ma fonction dans une société chimique transnationale m'a conduit à devenir le représentant de l'industrie chimique de l'ouest de l'Europe pour les questions de protection de l'environnement et, à ce titre, je suis devenu membre du Conseil de Direction du Centre International de l'Industrie pour l'Environnement. J'ai assisté, grâce à cela, aux deux conseils d'administration du Programme des Nations Unies pour l'Environnement le premier, à Genève le second à Nairobi (Kenya). Ces Conseils d'Administration ont été précédés par une assemblée mondiale des organisations non gouvernementales.

Il y en avait plus de 250. Je puis vous assurer que ces organisations, qui, si elles ne représentent peut-être toute la conscience du monde sont quand même son expression la plus organisée, sont absolument opposées à ces sources d'énergie qui comportent de graves dangers, et feront et font déjà pression sur les gouvernements pour que l'on s'adresse à d'autres types de solution. L'énergie solaire, on nous a dit que c'était lointain, 'énergie de fusion aussi (beaucoup de problèmes techniques sont paraît-il non résolus). Alors je voudrais terminer cet exposé par une véritable question que je pose aux spécialistes: lorsqu'on est devantl 'Assemblée mondiale des organisations non gouvernementales et même au Conseil d'Administration du Programme des Nations Uniespour l'Environnement, quelle est la solution au point de vue énergie que vous recommanderiez d'adopter pour qu'elle soit la moins polluante, la moins risquée possible et qu'elle puisse être acceptée par la conscience de l'humanité tout en nous donnant l'énergie dont nous aurons besoin?

DUBOS: The atmosphere being so gloomy, I shall present only two examples to illustrate that there is one component that we seem to eliminate from our projections into the future. Namely, that human beings are immensely adaptable and immensely inventive, and that has solved on many occasions problems probably much more difficult than the ones we are facing now. Since this would be too long to develop seriously as a theme, allow me to mention one tiny, small illustration of what human beings can do to make present institutions respond within a very short time—at times a matter of months—to a profound change in the total world picture. I happen to know Belgium quite well and I happen to have spent last week in Belgium at the conference concerned with agriculture and the environment. While travelling through Belgium I saw once more—as I have seen many times before—those immense greenhouses which the Belgians had built to grow some of the best table grapes in the world which they used to export to all of Europe. So I inquired about the production of grapes and was told that it had almost completely disappeared because of the new market conditions created by the Common Market. Now does that mean that the Belgians have been unable to adapt to this situation? far from it. Within a very short time they have discovered that with some very slight modifications of technique they can use the same equipment to produce a kind of crop that cannot be shipped from the southern countries, namely lettuce, and to some extent, tomatoes. So one sees that within a few years' time, a complete recasting of a kind of production to meet changing world conditions. Allow me to place myself in the United States for another trivial example. Last year, as many of you probably know, the price of beef increased enormously there. Within a very few months, the production of chicken and especially of broiler kind of chicken which can be organized in a few months, increased enormously, and people learned to eat broiler chicken instead of beef. The third example is a little more complex. But one that you will be able to see with your own eyes, I am convinced, within a very few years. Because of the increased cost of any form of energy, whatever or however it is being produced, it is obvious that the kind of buildings which have made all of modern architecture during the past 50 years, is absolutely incompatible because of the expenditure of energy that it implies—just imagine, we are in the middle of the day and we have to have light, we have to heat, or we have to cool, whereas we could very well save that energy. I happen to be very familiar with the planes of the United States and I suppose in the rest of Europe, but in the United States, in the schools of architecture, where one is not only learning but beginning to practice a different form of architecture, where the form of energy for better living and working conditions would be decreased, I am told by the architects and engineers who are working on this, by some 30%. So I mention these examples, not to document such a complex thesis but at least to give you some confidence that we human beings have faced many problems during the past 5000 years of civilized life but we have found ways of responding adaptively to all sorts of changing conditions and that we are doing it right now.

SIKKA: I am a geologist by profession. I shared the views expressed by my Nigerian colleague. I was going to talk more but he has covered most of the subjects. I should like to make a brief remark on some other aspect: 2300 million people so far have been providing the bulk of the mineral resources to support nearly 900 million people. The bulk of the future resources are going to come from the very countries who are called "underdeveloped." These are the countries which have the bulk of the population. Better understanding of the geological knowledge in these countries is going to lead to discoveries of many deposits. I do not share the view that we are running short of resources and that the cost to produce metal is going to increase.

On the contrary, we study many of the metals, cost has been nearly going down, neither is the energy content going to increase to the extent that it is going to affect the costs. But in most cases the energy content will go down. What is really needed is Secretary Kissinger's views which he gave to the sixth session of the General Assembly and we should consider them. Secretary Kissinger said: "We are prepared to facilitate the transfer of technology and assist industrialization. A healthy global economy requires that both consumers and producers escape from the cycle of raw materials surpluses and shortages which threatens all of the economy." I think we should view this statement here for the betterment of mankind.

NOGUCHI: Because of the time limitation I make a brief comment. Most of the energy resources have been localized in a sense, and this problem—as well as the transportation problem—should be taken into consideration in a global analysis of future energy systems in addition to the nature quantities and distribution of energy resources. The limit of growth has often been discussed recently, and this sophisticated problem contains many conflicting phases such as some countries may have the time and funds to develop alternative sources energy until the exhaustion of fossil fuels, while many of the developing countries have to face the difficulties in R & D on new sources of energy in finding the solution prior to an expected energy crisis. However, very few detailed analyses on the problems and the predictable factors related to zero and minus growth have been made satisfactorily. It seems very likely for mankind that we have to decelerate the growth in the future. This problem might be closely related to the analysis of the environment capacity. In Japan we are very poor in the sense of natural resources, while we have perhaps more than eight times the energy consumption per unit area than that of the United States and also seventy times of the world average. In 1973 it caused a serious problem in water, thermal air, and pollution. International cooperation on a problem of this type might be very feasible and accessible, while the international cooperation on the energy supply and demand might be complicated in the later part of R & D.

JOHANNAS: As you know, I come from a developing country with a population of 130 million people. I should like to comment on the proposal already made during the meeting, namely to reduce the rate of growth of population in developing countries and at the same time to reduce the rate of economic growth of developed countries.

With regard to the population growth of developing countries, I would like to stress here that most governments, if not all governments in developing countries, are well aware of this problem and have implemented one or another measure to cope with it. Whether these measures have succeeded in reducing the population growth is another matter. I believe that we really have to surmount tremendous difficulties to make this program a success.

The most difficult problem is the traditional attitude of the great mass of the population which is based on an agricultural way of life, where children are not considered as more mouths to be fed but as more hands to be used in the field. The second difficulty is that the great mass has no sense about the future. Their daily concern at present is: What will we have to eat today? having no time yet to think about tomorrow. How can this great mass of poor people have any sense about the future if there is not present yet? The first solution for the reduction of the population growth is to raise the standard of living of these people. Or in other words to do something what is meant with the word development. These people have to be educated if we want them to have any understanding about the future. I have to admit that is a difficult job to do. I myself have had some experience in this field. I have at home two women servants, a mother, and a daughter. It didn't matter how much I told them about birth control, they both continue producing children every other year. Maybe we have to concentrate on the formal education of their children. Therefore we have to cope with the reality that for some time to come the population of the developing countries will still be growing at a fast rate, and it will take some time when the program of population control will start to materialize.

I am not accusing anybody why we are in such a mess, and certainly will not accuse my parents, for instance, why I happen to be in this crowded world. I can tell you how it feels to be in a crowd because I am a member of a family of 14 children of which I am one of the oldest. It takes a tremendous effort and many sufferings to give them all a decent education.

With regard to continued economic growth at the same rate in the developed countries, I would like to pose the following questions: What are you seeking in more and more affluence? Are you trying, for instance, to make it possible for all your people to stay at the same type of hotel where we are staying now? By paying more and more you are not getting better and better services. You have to line up to get your breakfast, to get your key, or to pay your bill. This morning I am asking the question: Why are we not staying in the hotel near our conference hall? and get the answer that to get in there we have to line up for one year. Your body cannot take much more than what is needed for it to function. You can produce more and more beef but cannot eat all of it. People start to go on diet and now are going back to the so-called natural food. Or are you going to continue to produce more of which a great part is being wasted, polluting your environment? That is what is happening now. I have a strong belief that in the developed countries you can save more, putting you really in the position to help the developing countries in achieving their goals to develop their economies. And in that way, too, it will help in achieving the worldwide objective of reducing the population growth.

The question can be posed: In what way can cooperation between developed and developing countries be realised? As it happens now, developed countries have depleted their nonrenewable resources or at

least have some shortage of it. The developing countries still have their resources, which is waiting to be developed. This will increase their national income and their ability to develop their own economics by their own means in the long run.

Cooperation can be based on mutual need, and I would like to call this base of cooperation the concept of "resources sharing."

Developing countries have the natural resources that can be shared by developed countries. Developed countries have their scientific and technological knowhow that, hopefully, can be shared by the developing countries. I think that capital for development does not matter very much; it can be put by both partners jointly or supplied by one party only, and it is to be expected that everybody will receive a "fair share" depending on their inputs. How much will it be? I certainly do not know yet at the present time, but we can talk about that to find out.

RANDER: Thank you very much. I believe these words of direct advice we received during today's session will be appreciated and I am appreciative that you did express them. We will now adjourn.

Chapter VI

BIOLOGICAL BALANCE AND THERMAL MODIFICATIONS

Président: C. M. Tarzwell

CONTENTS

INTRODUCTION

C. M. TARZWELL

Box 159, Old Post Road, Wakefield, R.I., 02879, U.S.A.

I should like first to introduce the panel. Beginning on my far left is Professor Peres, the rapporteur, who will summarize our two days of deliberations giving our main conclusions and recommendations. Professor Peres is director of the Marine Station and of the Oceanographic Center at Marseille. Professor Golterman is in the Limnological Institute of the Netherlands. M. Balhoul is in the National Meteorological Service here in Paris. Professor Mihursky is at the Chesapeake Bay Laboratory, Natural Resources Institute, University of Maryland. Professor Hedgpeth is in the Marine Science Center at Newport, Oregon, and he is with Oregon State University. Professor Barnett is with the Scottish Marine Biological Association. This session differs from other sessions of this conference in that we are dealing with biological matters. Because the terms we use may mean different things to different people, I feel that one or two definitions are in order. This session is concerned with biological balance and thermal pollution. By biological balance we mean the relative abundance of the different species that make up a population. Of course we also call it the balance of nature. If this balance is disturbed or some element destroyed due to some action, it can cause a chain reaction that can have effects that are not anticipated and that may be far reaching. Thermal pollution is a term which is now widely used. To better define its meaning I would like first to define water pollution. When I speak of water pollution I am speaking only of effects due to man's activities. In this context, water pollution may be defined as the addition of any material or any change in the quality or character of a water which interferes with, lessens, or destroys a desired use or uses. If there is no harm to a desired use or uses there is no pollution.

However, it should be pointed out that what might not constitute pollution for one use may constitute pollution for another use or the reverse. Generally speaking, the shortest definition for pollution is too much, too much of anything. It could be too much distilled water in a stream or too much sea water at the upper end of an estuary or some other material. However, just the addition of some material, if it does not cause harm to a use, is not pollution. Therefore, thermal pollution must mean that there is enough heat added or taken away so that a desired use or uses of that water is harmed. Man has been able, over the ages to influence his environment through changes in land use or modification or destruction of the vegetative cover. Almost without exception man has carried on his activities with little or no regard to the effects of his activities on his environment or that of other organisms. We have checks and balances in nature. If something occurs that favors one species it may increase in numbers at the expense of another species. Or it may so increase in numbers as to dominate the population and push the other organisms aside even to the detriment of itself.

Species have come and gone in geological time. Man has now no predators. He has controlled to a large extent his parasites and disease. Man must therefore control his own population if he is going to live compatibly on this earth and continue to exist as a successful species. We have heard a great deal in recent years about thermal pollution. Due to the publicity given to the thermal electric generating plants I think most people feel that thermal pollution is synonymous with these plants. This is really not true. Some industries, especially the steel mills, have been releasing a good deal of heat for many years. We have another source of heat, the sun which has warmed out waters because of a number of man's activities. Deforestation, lumber drives, overgrazing, unwise agricultural practices, extensive and intensive drainage, road building and dams, have destroyed vegetative cover, increased erosion, decreased percolation into the soil, exposed the water to the sun and lowered the water table. We have less spring water coming in to keep the streams cool. There is more warm surface water. The streams have been opened up to the sun's action. The warming of streams this way has made a large percentage of our trout streams unfavorable for trout. Many former trout streams are now favorable for trout only in their headwater areas. So, I would like to point out that thermal pollution is not new and that it is not caused only by thermal electric plants. In fact, the warming effects due to those activities of man which I have enumerated, are up to the present time more important and more widespread than has been the effects of the thermal electric plants. However, they are the source of tremendous amounts of heat and will become even more important in the future. The discharge of waste heat to our water must be controlled. I would now like to call on our rapporteur, Professor Peres, who will summarize our deliberations, our conclusions, and our recommendations.

RAPPORT DU GROUPE MODIFICATIONS THERMIQUES ET ÉQUILIBRES BIOLOGIQUES

J. M. PERES

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Le groupe de travail "Modifications thermiques et équilibres biologiques" a tenu quatre séances de travail au cours desquelles ont été présentées, outre quatre rapports introductifs, 20 communications sur des sujets particuliers.

Le problème des modifications thermiques dans l'atmosphère et dans les eaux est certainement important, et l'on doit savoir gré à l'Institut de la Vie de l'avoir retenu parmi les thèmes de réflexion proposés aux participants de la présente conférence, bien que les effets n'en soient pas encore perçus avec acuité, sauf toutefois dans les eaux douces.

Au point de vue analytique, on est certes obligé de distinguer, dans ce rapport général, les effets sur les phénomènes atmosphériques et ceux sur les milieux aquatiques en général, mais il n'empêche que le problème des modifications thermiques a un caractère unitaire sur lequel je reviendrai en conclusion du présent rapport.

En ce qui concerne, tout d'abord, les problèmes relatifs aux rejets de chaleur dans l'atmosphère, il apparaît que les principaux facteurs de modifications du bilan thermique susceptibles d'être affectés, dans un futur proche, par les rejets soient les suivants:

1. l'ozone stratosphérique agissant sur l'effet d'écran exercé par ce gaz sur la pénétration des radiations solaires;
2. le gaz carbonique troposphérique, dont une augmentation de concentration a pour effet d'intensifier l'effet de serre;
3. les décharges d'énergie au sol, qu'elles soient issues des grandes agglomérations urbaines, des concentrations industrielles, de la présence de centrales de très grande puissance, etc.

Ce dernier facteur ne risque d'entrainer des effets de quelque importance, à l'échelle globale, qu'après l'an 2000. Néanmoins, il constitue déjà un facteur local important dont on ne peut dire, d'ailleurs, que l'effet total soit néfaste.

Les conséquences des effets découlant de l'action des deux premiers facteurs ne sont pas connues avec précision et les estimations varient dans des proportions considérables pour les raisons suivantes.

— La complexité des phénomènes atmosphériques est très grande, et, de plus, il est impossible de séparer les divers phénomènes; il faut prendre en compte un grand nombre de paramètres, variables dans l'espace et le temps, pour constituer un système cohérent de nature à permettre une description acceptable de l'atmosphère.

— Pour cette raison, les modèles ne sont pas satisfaisants: on étudie qualitativement et parfois quantitativement, les mécanismes élémentaires, mais on ne sait pas calculer des effets qualitatifs globaux, c'est-à-dire que l'on ne sait pas, ou que l'on sait mal, quel est le sens (élévation ou abaissement de la température) correspondant à une excitation donnée à travers tous les mécanismes de feedback (positif ou négatif) qu'elle engendre.

Il reste extrêmement difficile de définir un état normal de l'atmosphère, et, partant, de définir si et quand un changement de circulation atmosphérique peut être attribué sans conteste à l'activité humaine.

En conclusion, il apparaît que la situation présente, en ce qui concerne les rejets de chaleur dans l'atmosphère, puisse être résumée comme suit.

1—Pour la circulation générale de l'atmosphère, bien qu'un changement minime de la température moyenne à l'échelle globale soit lourd de conséquence, on peut dire que, au moment où le problème se posera à nous, après l'an 2000, les moyens scientifiques auront progressé suffisamment pour que des réponses fiables puissent être données aux questions qui se posent actuellement. Ceci postule, évidemment que, d'ici là, les nouvelles activités humaines, sources de pollution thermique soient sérieusement contrôlées, par exemple le rejet des oxydes d'azote dans la stratosphère.

Une juste appréciation de l'impact futur des rejets thermiques sur les phénomènes atmosphériques généraux implique donc: d'une part, une amélioration des observations, débouchant sur une connaissance plus approfondie des phénomènes naturels (quelles sont, par exemple, les causes de la sécheresse actuelle du Sahel);—d'autre part, un effort intensif de modélisation.

2—Les effets locaux sont importants et seront de plus en plus marqués; ils représentent actuellement les problèmes essentiels. Ces problèmes se posent à deux échelles différentes.

Les uns concernent des aires relativement limitées, comme par exemple, les phénomènes de verglas, ou d'aérosols salins (nuisibles à la végétation) sous le vent des tours de réfrigération de centrales ou d'autres industries. De tels effets peuvent être prévenus par la conception même des installations industrielles.

D'autres concernent des aires plus vastes, telles celles correspondant à des agglomérations urbaines ou à de vastes complexes industriels. Ces derniers problèmes impliquent une planification très stricte des projets d'implantations nouvelles, ainsi que des mesures correctives pour les ensembles existants.

En ce qui concerne ces effets locaux, à l'une et l'autre échelle, il apparaît que des résultats positifs peuvent être obtenus par une distribution rationnelle des sources de chaleur.

Les problèmes de rejets thermiques en milieu aquatique dont les conséquences apparaissent beaucoup plus immédiates, ont occupé trois des quatre séances de travail tenues par le groupe. Un large examen de ces problèmes avait déjà été fait lors de la réunion préparatoire de 1973 et tous les participants de la conférence peuvent trouver aux pages 318 et 319 du volume qui leur a été distribué, une sorte d'inventaire des conséquences biologiques et écologiques de ces rejets sur les environnements aquatiques, une liste de thèmes de recherches dont l'étude est recommandée, une esquisse d'une stratégie pour le futur, enfin une liste de recommandations.

Un essai de synthèse des résultats des travaux et discussions des séances tenues les 9 et 10 septembre permet de dégager un certain nombre de points nouveaux, ou qui ont fait l'objet de développements nouveaux. J'en retiendrai cinq.

1. DIVERSITÉ DES MODIFICATIONS THERMIQUES

La réunion préparatoire avait envisagé essentiellement les problèmes qu'on peut considérer comme correspondant à une pollution thermique *sensu stricto*, c'est-à-dire les effets des effluents d'eaux échauffées par diverses activités humaines ou de transit des organismes dans les installations. Or il apparaît que des conséquences graves quant aux peuplements des eaux douces peuvent résulter des méthodes de mise en valeur des sols cultivables qui ont été pratiquées pendant des décennies telles que la déforestation, le pâturage excessif, l'écobuage (pratique qui consiste à brûler les taillis pour préparer des prairies nouvelles), etc., ainsi que de la construction des barrages. Le Dr. Tarzwell traitera de ces problèmes dans quelques instants, mais le groupe considère que l'échauffement et souvent le tarissement, saisonnier ou définitif, de diverses collections d'eaux continentales, tel qu'il s'est produit dans divers pays développés représente un aspect particulier des altérations d'origine thermique des milieux aquatiques et mérite qu'on y porte attention, pour prévenir des évolutions analogues dans les régions, ou les pays, où il en est temps encore.

2. MÉCONNAISSANCE DE L'INFLUENCE DES VARIATIONS NATURELLES DE LA TEMPÉRATURE

Les conclusions que l'on peut tirer des études, tant expérimentales qu'en milieu naturel, quant aux conséquences des rejets thermiques sur l'ensemble des milieux aquatiques, sont souvent affectées d'une certaine incertitude en raison de l'insuffisance de nos connaissances sur la variabilité des écosystèmes résultant des fluctuations naturelles de la température, même à l'échelle saisonnière, mais surtout à plus long terme (variations pluriannuelles, pluridécennales), ainsi que des variations des écosystèmes qui sont corrélatives de fluctuations de la température d'une amplitude anormale.

3. NÉCESSITÉ DE RECHERCHES COORDONNÉES

Le groupe, tout en reconnaissant l'intérêt des données expérimentales relatives aux effets de l'élévation de température sur les divers processus physiologiques d'une espèce prise en particulier, considère que les investigations de cet ordre ne sont de nature à faire avancer les connaissances que dans la mesure où elles s'inscrivent dans un ensemble plus diversifié de recherches. Il apparaît, à ce propos, que trois points méritent d'être soulignés.

3.1. Choix des espèces à étudier

En principe, l'étude d'ordre autoécologique doit porter sur les espèces que l'on entend protéger contre les agressions thermiques. L'appréciation du degré d'importance écologique des espèces a fait l'objet d'une discussion approfondie et, dans cet ordre d'idées, il apparaît que quatre critères peuvent être retenus:

(a) espèces commercialisables;
(b) espèces quantitativement importantes;
(c) espèces jouant un rôle important dans le réseau trophique;
(d) espèces de valeur esthétique.

En fait, il arrive que des espèces abondantes soient sans intérêt, tant au plan de l'économie, qu'à celui du réseau trophique; ce critère paraît donc sujet à discussion.

En revanche, le point (c) exige qu'on lui accorde plus d'attention, notamment en ce qui concerne les altérations de la composition ou de la production de l'échelon trophique primaire par les effluents chauds, altérations qui peuvent modifier radicalement le flux d'énergie à la base de l'écosystème. Les conditions d'utilisation sous différentes températures de l'échelon 1aire par l'échelon 2aire, ainsi que celles portant sur la dégradation du matériel organique par les germes, méritent également qu'on s'y intéresse.

3.2. Cette dernière remarque conduit tout naturellement au deuxième aspect, trop négligé jusqu'ici, qui est la connaissance des mécanismes qui régissent le fonctionnement de l'écosystème. Il s'agit, certes, de recherches dites fondamentales, mais dont l'application aux problèmes pratiques est à terme relativement rapproché. C'est par une meilleure connaissance de la structure et du fonctionnement des écosystèmes que l'on élucidera les rapports trophiques, les rapports de compétition, les facteurs de diversité, etc., et qu'on parviendra à une meilleure évaluation de l'importance écologique des espèces dont on a discuté précédemment.

3.3 Au plan de la méthodologie, enfin, le groupe recommande une étroite coopération entre les expérimentateurs et les écologistes opérant sur le terrain. Les premiers devront porter une attention particulière aux effets sublétaux de l'élévation de température sur les êtres vivants et le choix des espèces servant aux expériences pourra s'inspirer des observations faites par les écologistes de terrain. Les modèles mathématiques, encore à leurs débuts dans ce domaine, peuvent présenter un certain intérêt prévisionnel, lorsqu'on dispose de données nombreuses sur les exigences et tolérances écologiques d'espèces à large répartition géographique.

4. PALLIATIFS DES EFFETS DE LA POLLUTION THERMIQUE EN MILIEU AQUATIQUE

4.1. L'existence d'une certaine adaptation à des températures assez élevées a été reconnue pour les populations de diverses espèces, soit que celles-ci aient une large répartition géographique, soit que l'adaptation soit saisonnière chez les espèces à cycle bref, soit encore qu'on ait pu démontrer l'existence d'un certain potentiel adaptatif de l'espèce par voie expérimentale. Ces observations ouvrent la voie à d'éventuelles opérations de transplantation ou de sélection, portant sur des espèces économiquement ou écologiquement "intéressantes", et les premiers essais dans ce sens ont déjà eu lieu.

4.2. Compte tenu du fait que les centrales (thermiques ordinaires ou nucléaires) posent déjà des problèmes d'altération de l'environnement très sérieux dans les eaux douces et prévisibles à terme assez rapproché sur les rivages marins, le groupe de travail a porté un intérêt particulier aux palliatifs immédiats des effets de la pollution thermique. Ceux-ci se répartissent en deux catégories: procédés de récupération de la chaleur gaspillée; —procédés visant à minimiser ces effets par une meilleure conception des installations les effets du rejet ou du transit.

Parmi les premiers, le groupe note que l'utilisation des effluents chauds pour des opérations d'aquaculture se heurte au fait que le volume des effluents dépasse en général de plusieurs ordres de magnitude la capacité de réception des installations d'aquaculture, sauf à consacrer à celles-ci des surfaces qui ne sont très généralement pas prises en considération au moment de la conception des centrales. De plus, l'eau échauffée ne peut

être utilisée qu'en dehors de la période estivale, sauf en région froide bien entendu. En ce qui concerne les effluents de centrales alimentées en eau douce, le groupe de travail a enregistré avec intérêt les résultats déjà obtenus au point de vue agricole et forestier, tant pour le chauffage des serres que pour l'irrigation ou l'injection dans le sol des effluents. En revanche, en ce qui concerne les autres opérations de récupération, il apparaît que les possibilités d'utilisation des effluents pour les usages domestiques ou industriels se heurtent à des problèmes de transport de l'eau chaude ou d'élévation de sa température par un système de pompe de chaleur. De même, la possibilité de combiner les installations de gazéification et les centrales à gaz reste encore incertaine. Etant donné le caractère limité des récupérations d'énergie gaspillée qui peuvent être assurées par les divers palliatifs qui viennent d'être énumérés, le groupe de travail estime qu'il est souhaitable de chercher à en associer plusieurs autour d'une même centrale.

En ce qui concerne les palliatifs de la seconde catégorie le groupe a enregistré avec satisfaction les études faites sur des dispositifs diffuseurs, mais exprimé le voeu que les études de diffusion en général soient intensifiées, ainsi que celles relatives aux dispositifs propres à diminuer l'aspiration des organismes au niveau des pompes. Des recherches de laboratoire devront être développées également sur les effets de la vitesse de circulation et de la durée d'exposition des organismes à des températures plus ou moins élevées au cours du passage dans les condenseurs. Le groupe insiste, enfin, sur le fait qu'une centrale en fonctionnement, à partir du moment où s'est établi un certain équilibre d'un écosystème plus ou moins modifié par le rejet thermique par rapport à l'équilibre originel, représente un élément de cet environnement dont on doit éviter qu'il ne présente des fluctuations excessives: l'arrêt brutal d'une centrale peut avoir, sur l'écosystème ainsi modifié et adapté, des conséquences catastrophiques, et il convient que, dans toute la mesure du possible, les centrales comportent un nombre de groupes tel qu'un arrêt simultané de tous soit pratiquement exclu.

5. STRATÉGIE POUR LE FUTUR

Le groupe de travail considère que la stratégie pour le futur des centrales refroidies par eau devrait s'inspirer des principes suivants.

5.1. Le choix des sites est primordial et ce choix devra impérativement tenir compte des considérations de protection de l'environnement. On devra toujours, entre plusieurs sites proposés, choisir celui qui réalise le meilleur compromis entre les aspects techniques, économiques et écologiques.

5.2. La construction de centrales de très grande puissance (plusieurs GW) pose des problèmes particuliers dûs à ce qu'il paraît difficile, sinon impossible, d'extrapoler à une centrale de 5 GW, les enseignements tirés de l'étude des effets d'une centrale de 1000 MW. Il apparaît indispensable de prévoirs dès maintenant la possibilité de placer à une certaine distance du rivage (offshore) les centrales "mammouth". (plusieurs dizaires de GW).

5.3. Eu égard à l'importance écologique des estuaires qui sont des zones privilégiées de transit de migrateurs, de fraie, de rassemblement de jeunes, mais aussi de véritables pièges pour certains polluants apportés par le réseau hydrographique, l'installation de centrales en milieu estuarien paraît devoir être proscrite, de même qu'au voisinage de lacs peu profonds.

5.4. La température ayant pour effet d'accroître l'intensité du métabolisme, l'élévation de température des eaux conduira, dans beaucoup de cas, à une influence accrue des polluants présents dans ces eaux: matériel organique, métaux et métalloïdes, détergents,

biocides, etc. Il importe donc que les centrales importantes, notamment celles refroidies à l'eau de mer, soient placées dans des sites éloignés des diverses sources de pollution, ce qui est d'ailleurs un argument supplémentaire en faveur de leur implantation offshore. Le problème du chlore utilisé pour la prévention des salissures dans les circuits d'eau de mer exige des recherches approfondies et l'absence totale de chlore résiduel au rejet est un impératif absolu. Par ailleurs, le maintien d'une certaine variation saisonnière de la température du milieu récepteur, possible à réaliser par dilution, paraît tout à fait nécessaire.

Ce dernier point a conduit le groupe de travail à insister sur le fait que l'eau ne devrait plus être utilisée comme un vecteur de polluants, que ceux-ci soient physiques, chimiques, ou représentés par du matériel en suspension. Dans le plan d'actions pour l'Humanité que va proposer l'Institut de la Vie, il est souhaitable que l'eau soit considérée, dans l'avenir, comme devant jouir de la même protection que les parcs nationaux. Certes, ceci ne peut être, pour l'instant qu'un voeu pieux, mais il importe de réfléchir dès maintenant à jeter les bases d'une nouvelle politique des rejets de toutes sortes, ce qui n'exclut nullement, bien au contraire, les problèmes de recyclage.

Dans une dernière partie, enfin, du rapport général il parait nécessaire de réinsérer les travaux du groupe dans le large contexte de la présente conférence, dont je rappelle que le thème est "Vers un plan d'actions pour l'humanité—Besoins et ressources—Méthodes de prévision."

En fait, il semble que, dans ce titre, le terme clef soit: "Besoins et ressources". Les ressources minérales et les ressources énergétiques sont du domaine de deux autres groupes de travail de cette conférence. Les ressources alimentaires, elles, sont le thème majeur des réflexions de nombreux organismes internationaux et les problèmes que posent leur conservation et leur expansion ont été évoqués à maintes reprises au cours des travaux de notre groupe. Ainsi apparaissent deux des besoins majeurs de l'humanité: le besoin en énergie et le besoin en ressources minérales—dont certaines sources d'énergie font partie d'ailleurs. Restent deux autres besoins à satisfaire, à savoir l'habitat, encore que le terme ne me plaise guère parce que trop restrictif, et que je lui préfère celui, plus écologique, de biotope, et aussi l'emploi.

Je laisserai de côté ce dernier besoin car je crains que l'évocation des problèmes qu'il pose ne nous entraîne trop loin du thème de la conférence. Néanmoins, je voudrais rappeler qu'on évalue pour l'ensemble du monde le nombre d'emplois nouveaux à créer chaque année à 280 millions. Notre siècle est celui des grands projets nationaux ou multinationaux. Ceux-ci sont généralement conçus en termes de développement et l'on s'efforce heureusement, de plus en plus, d'y introduire des clauses de respect de l'environnement, sur lesquelles je reviendrai tout à l'heure. Sans doute faudrait-il y inclure également des clauses relatives au nombre et à la diversité des emplois corrélatifs de ces projets.

Néanmoins de ces quatre besoins fondamentaux qui nous paraissent être ceux de l'Humanité, ceux relatifs aux divers biotopes de l'homme, c'est-à-dire à l'environnement qui est en quelque sorte la somme, ont plus particulièrement retenu l'attention de notre groupe. Certes nos travaux étaient orientés vers les effets des modifications thermiques, mais il s'agit là, somme toute, d'un facteur de pollution parmi d'autres. Non seulement les effets des activités humaines sur l'environnement sont multiples, mais encore ils sont interférents. Un plan d'actions pour pallier les effets des modifications thermiques ne peut être qu'un volet d'un plan général d'actions pour l'environnement et si je dis pour l'environnement, c'est parce qu'il s'agit bien, avant de protéger cet environnement, de le définir et de le comprendre.

Il a été dit par un des membres de notre groupe de travail qu'il importe avant tout, en ce qui concerne l'environnement de choisir les actions que l'on a le temps et les moyens d'entreprendre. L'expression de "conservation de la nature" doit s'entendre pour les parcs nationaux et celle, moins contraignante, de "protection de la nature" doit être conçue dans le sens du maintien, non pas d'un état qui était celui de l'environnement il y a deux siècles ou deux millénaires, mais dans le sens du maintien, ou de la recherche, d'un état d'équilibre de l'environnement qui soit compatible:—d'une part avec un certain agrément du cadre de vie de l'homme;—d'autre part avec certaines formes d'exploitation des ressources naturelles, et principalement de celles qui sont renouvelables.

Ainsi notre groupe de travail suggère-t-il d'insérer dans le plan d'actions pour l'Humanité que doit élaborer notre conférence, un certain nombre d'actions d'ordre très général et qui appellent, sans aucun doute, des avis et éventuellement des amendements de la part d'autres groupes.

1. Planification stricte du taux d'occupation des sols et de l'attribution de ceux-ci aux diverses activités de l'homme. On cherchera à définir un seuil maximal d'occupation des sols, fondé sur des paramètres de l'environnement (l'importance de la nappe phréatique pourrait être l'un de ceux-ci). L'institution d'une taxe progressive d'occupation des sols jusqu'à ce que soit atteint le seuil maximal pourrait être un élément efficace de la rationalisation de l'occupation de ces sols.

2. Incitation à économiser l'énergie: d'une part, par des mesures visant à la récupération de 50% de l'énergie gaspillée (dont des exemples ont été donnés précédemment); d'autre part, peut-être, également par une taxation progressive, jusqu'à une limite maximale, des demandes nouvelles en énergie.

3. Réalisation d'études régionales pluridisciplinaires, de nature à donner une idée aussi complète que possible de l'état actuel de l'environnement. Ces études devront tenir compte de la documentation la plus large possible (cf. point 4) et serviront de base à la conception des projets d'aménagement (cf. point 5).

4. Amélioration de la documentation. En matière d'environnement le pourcentage des études qui font l'objet d'une publication est excessivement faible, en regard du nombre de celles qui restent à l'état de rapports plus ou moins confidentiels ou à diffusion limitée, ce qui conduit à de regrettables duplications des recherches, génératrices de gaspillage de temps et d'argent. Il conviendrait d'instituer un dépôt obligatoire des travaux relatifs à l'environnement, par exemple au niveau régional ou provincial.

5. Coordination des opérations d'aménagement industriel ou assimilées. Il est indispensable que les grandes opérations d'aménagement fassent l'objet d'une coordination à long terme (20 ans par exemple) en liaison avec le plan d'occupation des sols (cf. point 1) de manière à ce que soient évaluées dans les meilleures conditions les interférences des divers éléments de l'opération sur l'environnement et ceci aussi bien pour les milieux aquatiques que pour l'atmosphère. Cette planification peut parfaitement être indépendante de la programmation graduelle du financement des divers éléments constitutifs de l'opération d'ensemble.

6. Le point 5 implique l'existence d'organismes consultatifs comportant des administrateurs, des ingénieurs et des scientifiques de diverses disciplines et notamment des écologistes et aussi des météorologistes (à peu près toujours oubliés), de manière à pouvoir dresser à l'intention du "décideur" un bilan complet des aspects techniques, écologiques, socio-économiques de l'opération projetée et des divers projets élaborés pour la mener à bien.

Les administrateurs et les ingénieurs doivent admettre que les écologistes sont pour eux des auxiliaires et des conseillers et non des adversaires a priori, mais que la protection de l'environnement telle qu'elle est proposée dans le présent rapport peut conduire à adopter une solution technique qui n'est pas forcément la moins onéreuse. Quel que soit le degré de développement d'un pays, il importe que les technologies qu'il adopte en matière de transformation d'énergie soient neutres vis-à-vis de l'environnement.

Sans pour autant s'associer à ceux qui prônent la croissance zéro, le groupe de travail tient néanmoins à émettre les plus expresses réserves sur les projections sur l'avenir, telles qu'elles sont fréquemment avancées à l'heure actuelle. La protection de l'environnement, non seulement contre les modifications thermiques, mais contre toutes les agressions et nuisances découlant des activités humaines, contraint dès aujourd'hui à s'interroger non seulement sur les dimensions qu'il convient de donner aux agglomérations urbaines ou aux complexes industriels, mais sur les principes généraux de l'aménagement de notre planète, sur l'évolution de sa démographie et de ses ressources, en bref sur les divers aspects de sa croissance au sens le plus général de ce terme dont il ne faut pas oublier, néanmoins, qu'il a un fondement essentiellement biologique: l'expansion numérique de l'espèce humaine.

L'accroissement de la quantité d'énergie disponible permet ou même stimule l'accroissement de la population et ce dernier ne peut se faire qu'au détriment d'autres espèces. La loi biologique suivant laquelle la diminution de la diversité spécifique entraîne une diminution de la stabilité du système n'est pas valable seulement au plan écologique, mais aussi au plan social et au plan économique.

Le but que s'est fixé et que nous a fixé l'Institut de la Vie est justement d'élaborer un plan d'actions pour l'Humanité afin de permettre la survie de notre espèce dans un monde meilleur et plus juste. Les changements de l'environnement étant inévitables, l'homme doit s'efforcer de les orienter à son profit et c'est vers ce but que doit tendre le plan d'actions de l'Institut de la Vie.

DISCUSSION

TARZWELL: Thank you, Professor Peres for so efficiently accomplishing this very difficult task of summarizing on such short notice the two days of discussions and reports of our committee. I should now like to proceed by asking each member of the panel if he has certain comments, additions, or suggestions. After that we will open the meeting to questions and suggestions from the floor. First I would like to call on Professor Golterman.

GOLTERMAN: Several of the points that come to mind have been mentioned by the rapporteur. I think we should be very grateful for the very good effort he has made in summarizing; but, nevertheless, there are several points, on the freshwater ecosystems especially, which should be emphasized. I think we should realize that when we are talking about freshwater we are talking about the situation in Europe more than what has been discussed about the situation in the United States. It has been said that the thermal pollution is part of the general pollution. We must realize that the changes in the ecosystem which we can notice at the moment, are going that fast that we as biologists can hardly keep in time in describing the changes that are taking place. They are not the changes that are going to take place in 100 or 200 years but the changes that will take place in 5 or even 10 years. It is quite clear that technology can solve all the problems of prevention of the pollution. I think it is just the same that technology can solve the problems we have been discussing this morning of the food shortage for the developing countries, and I am especially referring to Africa. If we use a very small quantity of the money that we have been using to send somebody to the moon for the irrigation of the Sahara there would be no problem for the food supply for Africa. But we always hear as biologists that society cannot raise the money to solve these problems. I think this is one of the important issues of a meeting like this. Why do we always decide on the wrong issue? The knowledge is there. We do know as biologists that we have to protect the environment, even if we do not understand how an ecosystem is being controlled, even if we do not understand the rate of growth of phytoplankton, the main organisms which are producing the energy for all the other compartments of the ecosystem. Nevertheless, we can control general pollution in Europe, and especially that due to the entrophication of our waters in which we put all the essential nutrients and fertilizers which India is lacking. This can easily be controlled as there are no technical problems. But we do not want to pay for that. We always hear that the cost of the prevention of pollution is so high that our society cannot afford it. But, nevertheless, the cost of the prevention of pollution is not much more than the money we spend on sweets or on smoking. So we come to the question: Why do we take wrong decisions? During the discussions in our group we quite often blamed the decision makers. We may call them politicians, we may call them decision makers, but I think we should realize that the decision makers are not a different species from people like ourselves which we have chosen to do the job which we feel they are doing very badly. Coming back to the problem of pollution it has been said that the time element is so important that we have to make the decision today. I do not think this is true for the thermal pollution. It is quite clear that in the case of thermal pollution there are alternatives, for instance the usage of the cooling tower. I think that as long as we do not understand the ecosystem—you must recognize that ecology is a very young discipline, perhaps only 10 or 20 years old—and that we are still discussing how an ecosystem is working. I think that the time element therefore does not come into the discussion. I think we have to accept that especially the freshwater cannot be used for the disposal of heat. Finally, I would like to raise the question of: What is this pollution? Our chairman has said that the definition of pollution depends on the usage we are making of a water body. I think that is a typical point of view of an engineer. As a biologist I think pollution should be defined on introducing a change in the ecosystem. Here, I think, it is important that the rapporteur has said that we should protect our waters, which is one of the main natural resources we need so very much, like, for example, the national parks in the United States. Let us realize that there is no shortage of drinking water; but there is a shortage of drinking water because we pollute the water; because we use water as a cheap way of transporting our waste. When we are talking at this meeting about the limits of growth, it is funny that economists are talking about limits of growth when they really mean the number of refrigerators and motorcars we can produce. For us as biologists, growth is related to life. I think that we should realize that, for example, in the water we are using for drinking water in The Netherlands are 20 or 50 pollutants which are really toxic. I think we should realize that we are really talking about limits of growth in the biological sense, and that if we are not going to be much more sensible than we have up until now, we shall quite easily poison a large structure of Europe.

BAHLOUL: Je passerai sur un plan un petit peu moins élevé pour ajouter une seule remarque à ce qui a été présenté par le Professeur Peres. Je voudrais simplement insister sur l'apport que les météorologistes peuvent avoir. Cet apport serait considérablement plus important si la planification pouvait être améliorée. Si, avant d'implanter une nouvelle centrale ou avant d'équiper un nouveau site industriel, l'avis des météorologistes pouvait être demandé, je pense qu'on pourrait, à l'aide de modifications mineures et de coûts très bas, apporter certaines améliorations. Ceci n'est généralement pas le cas et notre apport reste souvent très minime, pour cette raison. Je souhaiterais donc insister, ainsi que l'a fait le Professeur Peres sur la nécessité d'une meilleure planification d'équipement des sites.

MIHURSKY: I want to build on something Professor Golterman stated at the end of his presentation. He touched on the point that what we are dealing with fundamentally is a biological problem. He touched on the point of limits of growth and in many ways I firmly believe this and agree with what he said. These limits generally have a biological basis. That brings us to the point, the fact that I think the environmental priority is, indeed, our top priority. With that in mind, I am a little bit disturbed. I went through the list of attendants, the list of the people at the conference, and it comes out to about 288 individuals. I counted the group here this afternoon, and there are approximately 76 individuals. Our biological session had approximately 45 individuals. That leaves 51 individuals from the other segments of the meeting representing the other disciplines. I hope the biologists are not, indeed, just speaking to themselves again. Anyhow, with that in mind we should make another point. Regardless whether you represent an underdeveloped country, a developing country, or a highly developed, industrialized country, there are a few brutal facts that must be appreciated. Although we now appreciate their needs, we essentially developed environmentally neutral technologies. I think we agree that we cannot achieve a quality society without a quality environment. As a result we have witnessed socially unacceptable environmental degradation. Manmade energy conversion processes are not environmentally neutral technologies. The potential and real environmental dangers associated with manmade energy conversion processes to my mind dictate that we adopt as a future strategy for man, one that insists on following least-energy cost pathways to meet legitimate social needs. I think you will appreciate that we are not doing this at the present time. In order to follow that kind of procedure, I think we must also recognize that a new political format for decision making will be required. There is another very important series of linkages that I think support this point of view. Increased amounts of energy available to us permit an increased urge for development which in turn more easily justifies increased numbers of people. The consequence of that is biologically oriented here in that increased numbers of people and their activities as we have traditionally and historically seen, because of the kinds of economic and ecological philosophies that we have permitted to persist, these increased numbers end up in decreasing the amount and numbers of other species. What this means is that we are on the planet Earth decreasing species diversity in a biological sense. There is an emerging biological principle that with decreased diversity you have decreased stability with all the concommitant problems that ensue, that overlap into the social area. I think, those of you who are industrialists, I can appreciate that point of increasing diversity in your operations because what does this do? This increases stability for your organization. The reverse of that is the case, and that is what we are leading into or are into now in the biological sense with increased numbers of people.

HEDGPETH: I do have a few comments to make. This conference has consumed a lot of energy, and energy consumption is perhaps in its golden age. We may never have as much of it in the future, yet we have built all these large, elaborate, energy-consuming buildings. The poster displayed on the lectern reminds you of that. It shows a moonlit or smoggy view of Paris, of the Eiffel Tower dwarfed by a great high-rise box surmounted by the moon. There is some photographic trickery here with the lens, so it is difficult to decide just what building it is, but it is not at the Gare Montparnasse near our hotel. It is unfortunate that this should happen to Paris and here we are no different from New York. Some of us have been too warm here. I understand that we can either have this room too hot or too cold, but they do not seem to have a medium temperature adjustment. Is this supposed to be the Golden Age of Paris? Perhaps we had better skip that philosophical question, but what we have been talking about is a sort of Golden Age, an age of an improved environment, with comfort and food for all without destroying the environment.

Just before lunch, we heard remarks from our friends from Indonesia and Africa that perhaps we ought to slow down our rate of progress toward the Golden Age so that they could catch up with us or at least have a little of the goods of the world before we use them all up. That reminds me that something was said about our adaptability by Dr. Dubos. But, man's most unadaptable trait is avarice. Of all kinds. For shelter, for food, and for his own material benefit. I do not know how he is going to get rid of that. I guess that my Calvinistic background makes me a bit pessimistic on that point. So the question is: What are we willing to give up so that we can all share what remains? I asked the students: "We can't go on this way, we don't need air conditioning in Oregon, for man has lived thousands of years without air conditioning, in certain parts of the world, at least. What are you going to give up? I'll throw my TV set out of the window". They sat there and said nothing. That is the lack of adaptability of greed and avarice, I guess. These are very nasty words, I am afraid. I have a suggestion for the priority of our resolutions; I think it has already been alluded to a number of times. I put it this way: priority 1A is to preserve the process of photosynthesis. The Institut de la Vie, I presume, is concerned with the quality of life, and this quality, as has already been said several times, depends on the quality of the life that we share the earth with. Otherwise, we will reduce it to a shambles, to a situation in which only blue-green algae can live and some of them, as you know, can live in hot springs of 80°C. And those who say "we have not time to wait" or "we must rationally balance the costs and benefits and go ahead" stand, in my view, in profound contempt of nature. It is an anthropocentric lack of concern for the environment which is contrary to the spirit of this conference. I think there is one thing we did overlook in our discussions of thermal problems—I was reminded of this by several remarks, however. We know that in most life processes in the seas and coastal waters (and this is our concern primarily) reproduction goes on in great excess. Hundreds of thousands of millions and

billions of eggs and larvae are produced by almost everything except the higher vertebrates. Even the more slowly growing commercial fish produce hundreds of thousands of eggs per individual. I have heard it said by people concerned with power plants and factories: "Look, you're losing 99% of the process of reproduction anyhow. What's the difference if we're going to knock off a few more tenths of a percent or so?" The point is that if you succeed in hitting that at the wrong time of year you may knock off 100% The significance of this phenomenon of excess reproduction is that, in the sea (including the coastal zones and the estuaries) is a perilous and uncertain place for life to go on, and that the apparent excess of reproduction is adaptation to this perilous environment. The possibility exists that we can give the survivors one more little nudge and thereby put the last straw on the 1% of surviving larvae. We should not forget this possibility.

I should also like to comment on some remarks on the suggestion made that we encourage further development of coastal zones and estuaries. These are the most productive and, I suppose, in some places, the most pleasant places to live, although I do not find it very appealing to live in a mangrove swamp, but people do live in mangrove swamps and the world would be less interesting if we turned them all into industrial waterfronts.

I think we should consider that the priorities for the use of estuaries and coastal waters are what the greatest value of them for man's continued endurance on this planet may be. We can approach this from the historical viewpoint by remembering that man first came to the shore to gather food. So the first priority is the maintenance of these regions as food-producing areas, which could also include proper husbandry of such environments as salt marshes and mangrove swamps to the end of continuing them as environments for the natural processes that make them productive of food. And this is, of course, the natural use, the maintenance of the environment in an ecological sense.

The second thing we did as a species was to establish dwellings on the shore, to be near the source of food, and quite possibly to stabilize limited areas for the further production of food. The culture, or at least the attempt to control growth of shellfish—especially oysters, came not so long ago in terms of entire human history but nevertheless early in terms of sophisticated civilization. In our time, of course, there is a great premium on coastal property for people who can afford it as a place to live, and the pressure is so great that on some coasts we have massive hotels, apartment houses, and condominiums; all this reflects an early and long-standing use of the coastal region as a pleasant place to live.

The third use we made of the coast in terms of history was for commerce and navigation. Having established residence and production of food, there followed the need to communicate and trade.

The last use, and the use which should stand last in our sense of priority, is the use of coasts and estuaries as sewers and waste disposal sites. I do not consider this a justifiable priority, although I am aware that sanitary engineers [who are meeting concurrently in this same building, although there has been almost no communication, certainly not at an official level, with them] consider the use of coastal and estuarine waters for waste disposal a "positive benefit" to be reckoned along with the fisheries and dwelling sites as an economically justifiable use.

We affect our coastal regions in many ways, some of them not directly related to activities on the coast in coastal waters. The Aswan Dam has become a classic example. We are destroying, or have already destroyed, a valuable fish resource in the Delta of the Nile because the Aswan Dam has held back the silt needed to maintain the Delta and it is being eroded at a rapid pace and the sand is moving by littoral drift toward Israel. Perhaps the Israeli will win in the long run because of this movement of sediment away from the Nile Delta. There is another aspect, although not related to the coastal problem that we should remember, and that is that the impoundment of water behind the dam has greatly improved the environment for schistosomiasis. I understand that some Egyptians think that this is a fair exchange, 5000 or 6000 cases of schistosomiasis a year for the material progress brought by the Aswan Dam to their country. Everyone here knows that I do not believe in progress, so I need say nothing further at this time.

BARNETT: I should, of course, like to agree with much of what my colleagues have just said. They have covered many of the points I should have liked to have mentioned. But, in particular, I should like to agree with Dr. Golterman about the biologists' difficulty in keeping up with technological developments. This appears to be a very difficult problem for us. There is one aspect in Professor Pere's report which I think might be emphasized more, and this concerns the different effects of power stations in the seas of different parts of the world. Latitude is a most important consideration because in subtropical and tropical regions, where normal sea-water temperatures are high, marine organisms generally live at temperatures which, particularly during the summer months, are closer to the animals' lethal death points than in cooler waters. This is when the elevated temperatures from power stations and other sources can cause significant kills of marine organisms simply because there is not the scope for raising the temperatures. On the other hand, in higher, colder lattitudes, marine animals have a greater flexibility for tolerating small temperature increases. This latitudinal difference raises possible future problems for any of the developing countries which engage in programs of power-station construction. This does not mean to say that the temperate seas of the world can accept unlimited quantities of waste heat. As Professor Peres has remarked, we must be most careful about the siting of power stations. Although direct lethal effects are less likely to occur in temperate waters it is possible to get longer term effects which can affect different animals in different ways.

This emphasizes the need for planners and engineers to involve biologists right at the beginning of the planning stages of power stations. Certainly this now takes place, I believe, in Australia and the United Kingdom, and I should like to think that if other nations were to do this, many of the localized problems of heat pollution would not occur.

TARZWELL: I believe that before we open the discussion to the floor I should like to clear up some misunderstandings in regard to my definition of pollution: in it, use is stressed. We can classify our uses of water collectively under nine headings: domestic water uses (that is the domestic and municipal water supplies); agricultural uses (which include irrigation and stock watering); industrial uses (for cooling water and other purposes); and the use of all our waters by fish and other aquatic life that live in them. Included in this latter use is aquaculture. Other uses of our waters are recreation and aesthetic enjoyment. You cannot always set a monetary worth on aesthetic values but they are still very important. The remaining uses are for power, for water power, and for cooling water for the thermal electric plants, for navigation and for waste disposal. In a few instances the addition of organic wastes to a fishing water increases the fish production. If you have a very infertile water which is not being used as a source of drinking water and you add a small amount of sewage which fertilizes it so that more fish food organisms are produced which in turn results in an increased yield of fish, since your desired use was fishing, this addition of sewage does not constitute pollution. However, if your use of that water is for drinking, such an addition of sewage would be pollution. When the desired use of a water is for drinking, anything that interferes with that use is classified as pollution according to my definition.

We felt that we would like to organize this session so that there would be a maximum time for questions and comments from the floor. We are now ready to begin. Before you ask a question or make a comment would you please organize your material so you can present it logically and come directly to your point and make your statement as concise as possible. I will field your comments and questions and ask various members of the committee to reply, if a reply is necessary or if some of them feel that they would like to reply to it.

GIBRAT: J'ai assisté, il y a une quinzaine de jours, à un symposium à Oslo, qui avait exactement comme sujet celui que vous venez de traiter, et une des conclusions m'a paru intéressante à vous communiquer.

Nous étions à peu près moitié ingénieurs (c'est mon cas), moitié biologistes: la représentation des Etats-Unis était extrêmement importante et nous avons constaté que les études faites depuis six ou sept ans avaient conduit à la connaissance d'innombrables données ou études qu'il était malheureusement à peu près impossible de coordonner. Il apparaissait entre les résultats des contradictions considérables, et une des conclusions de la table ronde finale sur les rapports de l'environnement et des rejets thermiques a été que l'on devrait peut-être diminuer le nombre d'études locales faites de cette façon, et revenir à la biologie fondamentale; en particulier la confusion qui est apparue après cinq jours de séance et soixante ou 70 heures de réunion, était due à ce que nous ne savions presque rien sur les réactions des organismes aux faibles variations de température; probablement des études importantes dans cette direction permettraient d' mettre de l'ordre.

Le deuxième point était qu'il fallait distinguer très nettement entre les zones de mélange situées entre la sortie de l'eau chaude et le début d'une certaine diffusion, car là les effets étaient importants, les différences de température fortes, et on était, au fond, dans un ensemble de connaissance assez bien structuré qui permettait donc de proposer des réglementations. Par contre, si on dépassait cette zone de mélange et qu'on arrivait à des variations de température de l'ordre de un ou deux degrés par exemple, il fallait se défendre de toute réglementation générale et apprécier chaque problème, cas par cas.

TARZWELL: I think there has been some misunderstanding by some people with regard to the effects of temperature and also other pollutants such as toxicants. I would like to field part of this and then I will ask Dr. Mihursky to make a further statement if he so desires. We do not have to directly kill an organism in order to severely restrict it or eliminate it. I think this is not understood very well by nonbiologists. When we make a small change in temperature that puts a stress on a desired species and make environmental conditions more favorable for another species or several other species, they increase in numbers to such an extent that the desired species cannot compete so readily: that species goes down and the other species increase and we have a shift in the qualitative and quantitative makeup of the population. That is what might be spoken of as biological unbalance. I have seen this occur in trout streams; I have seen it occur in warm waters. I have seen the undesirable species replace the more desirable game and commercial species. It does not take very much of an increase in temperature to cause this change. Contrary to common belief and what I heard in one of the meetings here, it was felt that temperatures could be raised in the wintertime. The wintertime, for some areas, is one of the most critical: 1°C increase in temperature in a trout stream can change the time of emergence of the insects which are a basic food for the organisms. With a few degrees rise in temperature, insects that would normally emerge in late spring came out in January in some of the experiments carried out at the Environmental Protection Agency Water Quality Laboratory at Duluth. Not only do we have them emerging when it is not favorable, or when their food is not there, we also have change in the emergences times of the males and the females, such that with only a few degrees increase in temperature in the winter the males could emerge so early there would be no reproduction, with a drastic reduction in the species. In addition, many organisms require a cooling period in winter for the maturation

of their sex products. If the water temperature does not drop below a certain level, the sex products just do not develop. Others require very cold water for spawning, and others require—like the Atlantic salmon—very cold waters for the development of the eggs and fry. As to the lack of exact data on fine differentiations, I will agree with you because we have not carried on the right kind of research to get this. It has been very difficult to carry out the research needed to give the required answers. I find that some of the people who are most critical or who are finding the most fault with the biologists for not having the required data are the ones who in the past have controlled the purse-strings and did not fund recommended research. I know from personal experience that research projects detailing the kind of investigations that were needed in order to determine the water quality requirements for marine organisms and to supply the data which we now so sorely need were not approved. I have struggled for 25 years for the determination of water quality criteria to serve as the basis of water quality standards and the money that has been given to these projects in the past has been a drop in the bucket in comparison to the importance of the subject. I feel rather strongly on this because this has been a life-time objective and its handling has been a thing that has frustrated me for one-quarter of a century. I believe I should not say more.

MIHURSKY: I do not think Dr. Tarzwell has left much to be said. I made some quick notes here when M. Gibrat made his points, and I think all I can do is to agree with him on the need for organized studies then look at things from a regional point of view. In the United States what I have seen for the most part are small studies going on, sometimes being carried out by one individual looking at one aspect of the problem. I think what you must do is develop quantitative information that looks at the whole system that is being perturbed. I might hark back that Dr. Tarzwell, a number of years ago, when he was with a federal agency, had recommended dividing the United States up into a number of regions and within those regions identifying the most important organisms—and this is a broad definition of important organisms—then understaking the proper studies to determine the environmental requirements of these key organisms. In order to carry out that kind of plan, it is really a national plan and it requires national leadership. I dare say we did not receive the national leadership in the United States to carry out the plan suggested by Dr. Tarzwell. I think if we had carried out that plan we would have been in a better state at the present time to make decisions. Concerning the other point about mixing zones, that Dr. Gibrat mentioned, we have done a reasonable job in identifying the biological consequences in these areas of high impact, I agree. I also agree that our ability to predict what is happening in areas of low-grade heat, those abilities are very poor. Dr. Tarzwell did mention that; yes, we do know that changes can occur, especially if you are near the upper level of tolerance for a particular organism of a particular community. You can make those general statements, but if you are dealing with a particular esturian system or a river system, or an ecosystem and you have a specific site where you will perhaps want to locate a power plant and you have a number of alternative discharge designs that you can follow, a number of delta T options available to you, the size and extent of the plume, whether you want a small area of high-grade heat or a large area of low-grade heat—a number of options are available. When the biologist or ecologist is asked to quantitatively describe for that particular system what a large amount of low-grade heat means to that system, I dare say he cannot give an answer. Unfortunately, all I can say is that, yes, we need to do more work.

DOUDOROFF: I should like to make a few additional remarks concerning the objectives of water pollution control and concerning associated research needs. First of all, I would like to note that I am not personally in agreement with the view that our long range objective should be total protection of water resources from any change from a natural condition. Such total protection of water may often mean only increased pollution of air or land or increased use of energy and other resources. I am not only talking of thermal pollution here, I am talking of pollution in general. I think it should be recognized that to remove that last 1% of waste in some effluents requires a tremendous amount of energy as compared to, say, the removal of the first 95%. This increased pollution of air or land or use of energy resources could actually be more undesirable than the regulated alteration of water. The acceptable degree of alteration of water should be defined by biologists. And emphasis on basic biology, as suggested by the gentleman from France, I think is certainly highly desirable. I think there has not been enough emphasis on that. Dr. Tarzwell has given us his definition of pollution, which I think most biologists will accept, maybe with some reservations. The emphasis there has been on resources of value to man as food or for recreation, or in an aesthetic sense. But there are two schools of thought to be recognized among biologists, and these schools were both represented to some extent in our discussion group, although I must say we did not have anyone who held extreme views which are frequently expressed by environmentalists in the United States. One view represented in our discussion group is that aquatic communities are so complex and our understanding of interrelationships between organisms so incomplete that we cannot risk any considerable alteration of aquatic communities. A different view, and that happens to be my view, is that while our understanding of community relationship is admittedly deficient, we must begin to use such knowledge as we have acquired in some 25 years of fairly intensive research. That research, I admit, was not all that it should have been, as Dr. Tarzwell pointed out, but still there has been quite a bit of money spent in this area of water quality requirements of aquatic life, especially in the United States. Support of this research has not been lavish, as I said, but one may reasonably ask why it should be continued or increased, for another 50 years let us say, if it has not made it possible for us to arrive at any solid conclusions that can be of real value to the decision makers.

According to my view we must be prepared to accept a certain degree of risk—the risk that our predictions of biological effects may turn out to have been wrong. This is the only way to test our theoretical understanding and our predictions. The damage that can result from the error of our predictions will not usually be irreversible, especially where localized thermal pollution is concerned. We are not likely to wipe species off the face of the earth. In other words, when we find out that there is serious damage going on, something can be done about it later. But in finding out that there is damage we thought should not occur, we should learn something and we should have to look for the reasons why our predictions were wrong. Much additional research is needed, not only in the water quality requirements of the individual species but also in the area of bioenergetics and trophic or nutritional dynamics of aquatic communities or ecosystems so we can better understand what organisms are really important to man in some indirect way as, for example, in the food chain, and which ones are not being perhaps just blind alleys in the flow of energy in aquatic systems. Not enough attention has been given to this area in the past, to trophic dynamics of aquatic systems. But let us not insist that we must achieve 100% understanding of the interrelationship before we venture into any predictive conclusions and take a few risks. Only by making some mistakes can we really find out in just what ways and on what questions our knowledge and our theory are deficient or incorrect.

GOLTERMAN: I think I heartily agree with you, Dr. Doudoroff, about the last percent of the sewage which cannot be treated. But when we say that we want the protection of the waters like the national parks, you should not forget that we accept recreation in national parks. But what we are talking about in Europe is not that last percent but, let us say, the first 95%. I think that you should be well aware that when you make a statement that we can accept 1%, the general public will say that if all biologists are willing to allow us 1% we can then easily dispose of 10 or 20%. I think our problem, at least in Europe, is to get rid of the 95% of the sewage.

BRODFED: I should like to make a comment, building on what Mr. Doudoroff said relative to what is an acceptable risk, and also relating to that part of the general report where it was mentioned that ecologists should try to educate engineers and administrators. It seems to me that in the way it was phrased in the report, biologists have been somehow pitted against engineers and administrators. It seems to me in effect that biologists should work very closely *with* engineers. I am an engineer myself and I have seen engineers learning considerably from biologists in recent years. I have seen engineers understanding that wiping out a species is not the only problem one should be concerned about; that lethal effects are not the only important thing; understanding the importance of entrapment and entrainment; and understanding that there are some sites that really cannot be used for power plants. But I should like to see a greater emphasis on the learning process in the biologists' community, particularly in terms of what the engineering profession can achieve. I have seen in the last few years many engineering concepts that can mitigate thermal effects, improved intake arrangements, and, in general, improved environmental control systems. I strongly feel that if biologists worked more closely in the initial phases of projects with engineers, they would be able to impart a better direction to those projects. I am not saying that each site can be used, of course. I am saying that for those sites that can be used, biologists should cooperate with engineers in determining how to use them wisely. Therefore, it is important for biologists not to take a position which is somehow separated from engineers, since these two professions are, or should be, equally committed in protecting the environment.

DOUDOROFF: I should just like to explain that I was talking about long range objectives, not about the relatively short range objectives, so I do not think that we are really in disagreement. But in the United States we have actually a national policy right now by 1985 to eliminate all pollutants. This, of course, is not going to be achieved, but this has been declared a national policy, and I have been directing my comments pretty much against that sort of thing.

YAROSH: I should like to clarify one statement that was made about waste heat. Perhaps I should better define what we mean by waste heat. Generally it is defined to be heat discharged at such a low temperature that its normal use is not considered to be economical. Power plants discharge very large quantities of waste heat and in the discussion we had on thermal modifications it was pointed out that utilization of this energy can be achieved. It should also be pointed out that, in general, utilization of waste heat does not solve thermal discharge problems. But what it might permit is the effective use of energy which we now discharge to the biosphere and do not use. It might permit the use of that energy in an area that is important. That is, it might permit the expansion, for example, of food supplies, either by improving the rate of growth of aquatic organisms by aquaculture and meraculture (and this is being done now, but not on nearly as large a scale as it could be), or by enclosed environmental techniques—the use of waste heat in greenhouses, for example—or by the use of waste heat in outdoor agriculture to extend the growing season. This also has been demonstrated and can be very important because it can expand the production of food supplies in some areas, particularly northern climates, where that expansion could be useful. Let me make a couple of other comments while I have the opportunity. These are in an area where they do not only fit this session, but they seem to fall between sessions and yet are important. I think that ecologists and biologists must be interested in the precursors of thermal discharge, that is, the use of energy. I am making an appeal and I should like to see a recommendation from this conference for a strong statement on the essential need to improve energy utilization. I think that in the same way that much of the additional energy research that

was discussed this morning—alternative energy sources—that might be carried out in the developed countries, in the same way, I think it is incumbent on the developed countries to be in the forefront of developing much more effective ways of utilizing energy. Let me give you some specific examples of how that can be done. They are not trivial. In the United States approximately 41% of all energy is used in industry. Of that amount, 17% of the total energy is used by industry as processed steam. We know technically that if we combine the energy-using facilities with the energy-generating facilities, we can make significant improvements in energy efficiency. For example—and there are a number of operating examples in the United States and elsewhere—improvements from 30 to 40% efficiency up to the range of 50–60% efficiency in the use of energy. The effect of this is to be able to accomplish the same desired human activities with a very significant reduction of the discharge of heat to the biosphere. That, after all, is what you people have been talking about: the effect of thermal discharge to the biosphere. I think that it is important that you, as biologists and ecologists, take a strong and active interest in promoting and advocating techniques of this sort. This morning, as another example, Professor Dubos suggested that buildings, such as the one we all are sitting in now, and the one that most of us are housed in in the evening, use too much energy. There have been several recent studies which conclude that modern commercial buildings use between 20 and 80% more energy than would be required if they were designed with energy in mind from the beginning. Such energy discharge to the atmosphere causes some of the problems that the rapporteur has referred to in the previous discussion. By insisting on new methods of design, by insisting on new codes and standards, I think the biologists and the ecologists, along with the architects and engineers, can more immediately bring about the types of changes we are all seeking. I worry about my biology and ecology friends retreating to the research laboratories and not actively participating in advocating some of the things I have talked about because I think they can be effective over the next 5 or 10 or 20 years. This is the critical period that was discussed this morning.

AUBERT: Je voudrais faire d'abord une remarque: plusieurs fois à propos de questions générales et qui ne touchaient pas uniquement aux problèmes thermiques, il a été question de l'importance des estuaires, zones côtières, etc. Il se trouve qu'il s'agit là aussi d'un sujet de recherches coordonnées, lancé dans le cadre du programme international des Nations Unies, sur l'Homme et la Biosphère (MAB). Mon intervention porte aussi sur un second point: dans ses remarques générales, le Professeur Peres, rapporteur, a fait allusion à ce qu'il a appelé le taux d'occupation du sol, et, si j'ai bien compris, à une définition d'un taux optimum d'occupation du sol. Est-ce qu'il peut nous indiquer d'une façon plus claire ce qu'il entend par là et préciser comment il est possible de définir un taux d'occupation ou d'utilisation optimum du sol?

YAROSH: I think I can perhaps answer that question. In Florida we have an extremely rapid growth rate both in population (last year a 4.5% growth increase) and particularly in energy (electrical energy, 11% per year). We are very concerned about how long this can continue, so we have passed in our State legislature a growth policy. In that growth policy there is a statement that an analysis will be made of what is called the "carrying capacity" of the land in order to determine the optimum types of uses which can be made for the land, whether residential development, industrial development of various sorts, commercial development, or recreational. In the consideration of the carrying capacity one must consider the natural systems, for example, the water table levels, the amount of water in the aquifers, the type of soil that exists, the type of vegetation, whether it is a wetland, whether it is an area that contains estuaries, or what have you. So we have now on the books as part of our State law a requirement that this carrying capacity of the land be one of the things that be determined before development be allowed to proceed.

TARZWELL: I have here a request from one of the panel members, Dr. Hedgpeth, after which we will take up the next question.

HEDGPETH: I should just like to make a brief comment on Professor Doudoroff's comment. While I do not believe in progress, I realize that it is impossible to stop interacting with the system in which we live, and, of course, this is essentially what we are talking about. I am reminded that there is another kind of pollution—at least another definition of pollution—and that, of course, is fishing. We are tampering with natural ecosystems, and we have been doing this for a long time. A good deal of what we know about ecology and the natural system comes from our study of fishing and fish population under exploitation. I quite agree with Professor Doudoroff that we are learning even more from what we are doing with other forms of pollution than commercial fishing.

JOY: I have to agree with Professor Golterman. I do not know much about sewage, but I am prepared to accept his word that it is the 95% you are worried about and that even the remaining few percent is dangerous. But in defence of Professor Doudoroff this is not so in relation to mining wastes and mining effluents, where it is the remaining few parts per million which are the extremely difficult fractions to remove. That is just one statement. Another statement is the influence of the interaction of biologists with the mining industry. As an example, there is a river in Cornwall known as the Red River because for 200 years the mines have been letting mine waters containing colloidal iron oxides into it. In the meantime a reed swamp has grown up at the point of discharge into the sea; it is quite easily seen that beyond the reed swamp there is practically no pollution because the reed swamp has developed some type of ecology of its own which succeeds in collecting and precipitating the very fine particles. Local environmentalists are now proposing to cut a channel through this swamp and are asking the technologists to discover a way of removing these

few hundred ppm of iron oxides. The converse thing has happened in the United States in the last three years at Boss Bixby where in fact they have built algae lagoons for the very special purpose of entrapping the waste chemicals and fine solids before passing into the river. So we find it rather difficult to know whether the biologists are for, against, or just with us.

OBREBSKY: I should like to make a few remarks concerning some aspects of ecology. Although the idea that stability of ecosystems is increased with increasing diversity has been a part of standard ecological theory in the past, I doubt that a current review of either the theoretical or experimental literature would unanimously support that view today. Some recent theoretical and experimental research suggests that some rather low diversity systems are more stable. However, we must also remember that the concept of stability itself is hard to define and the concept of balance of nature is ambiguous and should be critically examined by further theoretical and experimental research. I think we should continue basic research in ecology and ecological theory to remove the many ambiguities from basic concepts. Although it is attractive to argue that diversity increases stability, in arguments against pollution perhaps stronger arguments for taking care not to pollute the environment will ensue from future—more realistic understanding of the dynamics of ecosystems. I would emphasize the necessity for continuing basic research in theoretical ecology. I think that this particular issue has been underemphasized in the discussions that we have had in the last week.

HEDGPETH: Thank you. May I make one comment to that? I think it is unfortunate that we have had to coincide with the first International Congress of Theoretical Ecology being held in The Hague on identical dates. It would have been nice to interact, or to have these meetings back to back, not simultaneously.

LEWIS: But I think I should speak rather as a scientist, an international scientist, having been connected with the international atomic energy agency in their technical program for 15 years or so. This has had a large hydrological component. What worries me about this meeting this afternoon, although my worry is diminishing because it appears that there are plenty of people to speak, to defuse the confrontation atmosphere that came from the panel, because we must work together. I have a couple of problems—engineering problems in this case. One is that the St. Lawrence Seaway can be kept open in the winter—not iced over. The study of this had been done before the war, before the seaway existed. It is quite a difficult problem but it is one in which the engineer and the biologist must work together. Because there is going to be plenty of cold water and the great trouble is to conserve heat, the water out in the bays—and bays are not just shallow waters—will be cold still. In fact, hardly changed, I expect. It is only a narrow channel that will be kept open. But this is a matter of getting a compromise between the biological health of the river throughout the year and the use for transportation. One can quarrel with the objective one way or another but it is a very real problem that really involves cooperation, and I think it involves more than just biologists and engineers. I happen to come of a family that has been concerned with waterworks engineering in England, India, and Australia, and I can see, I should say, some advantages from things that have happened in this engineering but there also have been things that went wrong. So that we must work together, surely.

TARZWELL: If I could make a comment. Water under the ice at 32°F would not necessarily be much different than water from which the ice has been removed. It could still be 32°F or a little bit above. I do not know of any freshwater organisms that require temperatures below 34°F—there may be some, I may be ignorant of their requirements.

JASKE: I am stimulated to raise a question of organization in the conference by reaction of the panel—the one point I consider extremely important. In the reports of the previous groups—notably the energetics group—we heard a rather optimistic report by Dr. Kellogg on long range atmospheric modifications. However, even in the resources group, while there was an extremely good attention placed on the things that they did consider, it seems that the atmospheric features of power generation have really not been as broadly covered in the conference as perhaps they could be. I am concerned that we are leaving a set of open loops here which might lead the readers of the final proceedings to a conclusion that we really did not . . . that we really believed that the atmospheric problem would cure itself. Perhaps it might. I start with this logic by seeing no reaction from the panel to the point that was raised by Dr. Kellogg that it might be very dandy to warm up the whole world by several degrees. We did in fact hear some reactions of the panel to some very minor changes in temperature as being potentially dangerous, but on the notion of warming up the whole world we heard very little. It is along these same lines that I point out again to the panel the remarks that I made in the panel which indicated that in the United States some of the thermal projections and the forecasts for limited areas, which is the Boston-Washington area, do in fact when modeled, with models that have some credibility, indicate that areas as large as 50 000 square kilometers could be heated as much as 5° or 2.8°C on the average, and in the detailed areas around the city, perhaps as much as 3.9°C. These figures are supported by recent Japanese studies which I have received. These seem like some very significant things. I would also like to indicate that the study of equilibrium processes between air and water would lead one to conclude that the water temperatures of this same area would be increased by approximately the same amount. So, again, I am left hanging here as to what this conference is really going to conclude in the questions of air-atmospheric pollution, particularly thermal pollution in regard to this very important question of temperature increases. To repeat myself, the biologists present have made a

big point over sublethal effects and minor incremental temperature differential, but have really not reacted to regional temperature modifications of wide scale. Along this same line, to conclude a supporting point, while it may have been mentioned in sessions that I did not attend, I heard nothing on the international transport of sulfur oxide which is already acknowledged to be a very major problem in Europe. We hear of statues dissolving and works of art being destroyed in some countries, acid lakes forming in Scandinavia, and the resources people—again all of them did an admirable job—seem to lose the opportunity in examining the fantastic scale of the fuel problem to consider the mining of fuel before it is used for resource-valuable materials. I should like to point out that, for instance, in the United States we provide government subsidies to mine sulfur using the Frasch process and achieve some 9 to 10 million tons a year to do this. We then go around and we discharge approximately 11–14 million tons of sulfur a year through stacks which we are now prepared to scrub out at a 6% total energy penalty on the system. The reason why it is stated that recovery is not practicable is because the price of sulfur is too low. I have in that example a really difficult problem to resolve. On the one hand, we have government stimulating activity and, on the other hand, we have the government penalizing activity, all in the same material. This can be extended to others—vanadium etc. There is a whole host of materials in fuel which go up the stack. I would like to conclude that this perhaps is not the proper panel, but due to all these open loops I do not know which panel would really be concerned about it. This conference should make the major recommendations that the international position on fuels move toward the head end or pretreatment of fuels before burning as an international objective in order to achieve optimum resource recovery and the utilization of minerals which are otherwise blown up the stack.

BAHLOUL: Oui, vous vous êtes inquiétés des préoccupations de la conférence au sujet de la pollution atmosphérique et des mouvements atmosphériques. Je voudrais d'abord vous dire que, en ce qui concerne les mouvements à l'échelle globale, s'il est exact que si l'on rentre dans le cycle des modifications, on risque de provoquer des modifications irréversibles qui demanderaient ensuite des milliers d'années pour un retour à la normale. En fonction pourtant de la production de l'énergie sur la planète d'ici l'an 2000, on peut considérer qu'il y a assez peu de risques de provoquer un changement important de la circulation générale de l'atmosphère. Je pense que tous les spécialistes sont d'accord. Par contre, vous avez raison d'insister sur la notion de qualité de l'air, au même titre que sur la notion de qualité de l'eau. En particulier, vous avez parlé des climats locaux et des conséquences. L'un des sujets abondamment traités a été celui des centrales nucléaires. On peut effectivement prendre le problème de deux manières, soit regarder quel est l'effet moyen sur l'atmosphère et cet effet est tout à fait raisonnable, soit; chercher s'il ne peut pas y avoir d'accidents atmosphériques.

Evidemment, suivant qu'on prend le problème sous un angle ou l'autre, on peut être confiant ou dire que des accidents météorologiques sont possibles. Je crois que, dans l'état actuel des connaissances, on ne peut pas conclure. Les microclimats et les climats locaux sont étudiés, les effets sont parfois bénéfiques, parfois néfastes, mais en ce qui concerne les effets très nettement néfastes, à part la pollution on n'en a pas mis encore en évidence. Les effets néfastes, en ce qui concerne la qualité de l'air, proviennent du rôle joué par l'atmosphère pour transporter des polluants. Ceux qui en sont la cause sont les gens qui envoient des polluants dans l'air, et vous avez cité le cas important en Europe du SO2.

En ce qui concerne l'aspect météorologique du problème, en tant que techniciens, nous pouvons seulement dire que l'on peut appréhender ce problème correctement, c'est-à-dire qu'on peut faire des estimations assez précises en fonction de la provenance du SO_2, quant à la destination où arrivera ce SO_2. Donc nous considérons qu'en tant que techniciens, le problème est non pas résolu mais en bonne voie. Le problème doit être mis ensuite entre les mains de gens qui prennent la décision. En tout cas, je vous remercie d'avoir souligné la notion de qualité de l'air, au même titre que la notion de qualité de l'eau.

GONZÁLEZ: I want to express just two words of support to the previous statement made by Dr. Mihursky. It is that an increase of diversity is tied to an increase in stability. We should also realize that according to this concept an increase in diversity is accompanied by an increase in maturity. This is also manifested in society and, therefore, I think that this maturity in our society should be reflected in better communication.

CAIRNS: I speak not from the point of view of a biologist since I am not one, but I must say that I have been disappointed in our sessions at the apparent lack of communications between people like myself who are familiar with the coastal environment from the point of view of the physics of the environment and with the biologists. I think that we could both benefit greatly by increased interaction.

ROSS: First, may I please waste 10 seconds by congratulating you and your colleagues for keeping your speeches short and setting us a good example. Mr. Jaske made some remarks about sulfur dioxide pollution. This was discussed in one of the sessions. I should only like to say now that there are few ways of wasting more money than in trying to prevent the emission of sulfur dioxide into the atmosphere. Thirdly, I should like to appear to disagree with Dr. Golterman without actually doing so. He called for cooling towers wherever freshwater is needed for cooling. I think that in the present European situation he is probably right except for Finland and Sweden where lakes large enough for direct cooling may still exist. But when it comes to putting cooling towers on the shores of Lake Michigan, it seems to be complete nonsense.

GOLTERMAN: Concerning the issue of the Great Lakes. It has also been said that the Great Lakes can also be used for disposal of all kinds of nutrients but it has become quite clear during the last two or three

years that the biological changes that are becoming apparent at the moment in the Great Lakes should not be neglected. I am not so sure that with the extra influence of temperature it is indeed going to have no effect. As long as we are not sure, I would rather prefer the cooling tower.

HEALING: One of your distinguished colleagues kindly invited interest from other disciplines. As an example of this, may I ask, please, whether your working group or perhaps biologists in general have given any consideration to the possible ecological effects—favorable or otherwise—of the largescale mining of manganese nodules that is about to take place on the deep sea bed? I am thinking, of course, not only of the disturbance of the sea bed itself but the associated disturbance of oceanic waters. I would be interested to know if this is the sort of thing that biologists concern themselves with or possibly could monitor?

HEDGPETH: May I make a comment there? There is considerable concern for the effect of this activity on bottom communities in the deeper sea because it is suspected that they are of very long duration and have slow turnover rates. And that one mining episode may indeed have very permanent effects. Professor H. L. Sanders, at Woods Hole, and his people are devoting some attention to this. Also, Dr. Robert Hessler at Scripps. But the deep sea is not represented here.

PEARCE: Thank you. I was just invited, I gather, to make a comment. I do know that the United States Geological Survey has a large group which is concerned with the possible impact of mining magnesium nodules in the Pacific. As Dr. Hedgpeth suggested, they are talking to consultants at the present time and I believe are organizing a research group. There is also concern in terms of what offshore oil drilling and exploration will do to marine communities, and there are several research programs underway or proposed at the present time which are concerned with the recovery of minerals from the sea floor. Some of our representatives in Congress have suggested research programs which will consider the totality of the effects of offshore mineral exploration (Senator Clifford Case, New Jersey, has recently been responsible for such a comprehensive study off the New Jersey shoreline).

HEINLE: I wanted to make just a brief comment on a theme that we have heard in some of the other sessions but seem to have gotten away from here. We referred on several occasions to the quality of life and the necessity for preserving it. I hark back again to the developing countries who still have, perhaps, more commune with nature than they wish, whereas we who have achieved a quality of life have perhaps destroyed more than we wish. I would only like to hope that some sort of balance can be achieved in that they can learn something from us but not be denied the development they need.

ROESSLER: Relevant to that comment, I have worked in Florida in the tropics and there we have seen an increase of one or two degrees Celsius cause damage in the summer to the local biota. We have also seen depression in the biota just by the natural temperatures in the summertime. I would like to mention, for the developing nations' people here that the University of Miami and the University of South Florida have worked in a subtropical region; the University of Puerto Rico, the University of Hawaii, the University of Guam, and, I believe, some people in Pelau have done work in the tropics. It is extremely important to consider where in the tropics a person sites a power plant and to try to stay out of the shallow estuaries where grass beds and mangroves contribute high productivity. I would advise you to get these reports, which are rather hard to find; as Dr. Peres says, some of them are just grey literature, just laboratory reports, but I think it would be worth your effort to try and get them.

DALCQ: I would like to make some small comments. I was delighted to hear as a chemist representing the chemical industry of western Europe, from the point of view of the protection of the environment. I was delighted to hear the definition given by the distinguished rapporteur, Professor Peres on the protection of nature, which I noted, as being—if I may allow myself in a free translation—the search for a state of equilibrium of the environment which would be compatible with a certain enjoyment by man of this environment and of a certain form of exploiting natural resources—and especially the renewable ones. I was very puzzled by the next declaration of Dr. Golterman. I noticed from Professor Peres's exposition that the ecologists had to improve their image in the public and by industrialists and so on. Really, if the ecologists as such and the environmentalists can go on with exacting to prohibit any change of any system—and especially the water—they will not be followed, because it is too difficult, and when it is too difficult you cannot convince people. Now let us be realistic, as this gentleman from America said. You biologists are too modest. You know a lot of things and you always declare that you do not know. When we ask you for an advice, you always answer us, that it is variable, it may be so and so, it depends on the estuary, it depends on the water, and so on and so on. Now the governments are not doing so. They are taking decisions because there is a need of immediate action for the protection of our environment. Just to go back to the thermal pollution. I am a member of a governmental panel for a new law we are preparing and working on in my country. There was, of course, a discussion about the temperatures of rivers because it is a very big problem to know whether you have coolness in your electrical power plants or not. So what did we do? We took all the specifications of other countries—there were 19C, 20C, 23C, 25C—25C with the exception of 29C—22 with the exception of ± 5 during one week or during one month, and so on and so on. So without having any justification of what we should really do . . . but these differences of 1, 2 3, or 4 grades have a terrible impact on future investment in industry. I would ask the question—I know that you are more preoccupied by long range planning than by short range decision, but I should ask you if you would not be able to make a nice table with the knowledge you have about the normal, bearable limits of temperature in the rivers with

some differentiation perhaps for salmon needs and other kinds of fish with the seasons and so on. This would help very, very much the decision makers to whom you say that they decide without knowing. But they cannot do anything if you do not tell them. In the last recommendations of Professor Peres, one was that there was an exchange of information. I just want to quote you that in our industry we have this exchange of information of nonpublished things, nonpublished facts about the environment. It is functioning very well and should be encouraged on all levels.

TARZWELL: Thank you. After one remark I should like to turn the microphone over to Dr. Mihursky. I think there is one thing that you should remember. You were speaking of different temperatures. There is a natural daily and seasonal variation or cycle of temperature. The organisms that have survived are the ones that have been successful in adapting to the environment and now make up the present biota. They had to adapt to these daily and seasonal changes with temperatures increasing in the spring, being highest in the summer, decreasing in the fall, and being lowest in the winter. Finally, through geological time the temperature fluctuations and variations to which they became adapted have now become their environmental requirements. Therefore, if you are suggesting the favorable temperature for a certain species or a group of animals you must consider the temperature requirements for the different seasons of the year. Maybe it is this cycle of temperature which is now required that is responsible for some of the trouble you have run into. I would now like to suggest that Dr. Mihursky continues.

MIHURSKY: Yes, with regard to the points you made—and there were a number of them—I think you misunderstood a key point that I made in my statement. I think this may have been bothering you. I said we must follow a least energy cost pathway to meet legitimate social needs. In order to follow that pathway I am not saying it means no change. No way, or at no time in the past in my career as an ecologist have I insisted on no change. I have operated as a realist—which I think one must operate in that manner, or else you cannot be effective. If you say you cannot do anything, you are not going to be listened to. Along those lines I have worked with engineers for approximately 20 years concerning power plants and their designs in siting operations, and I think we have, indeed, affected changes that have been for the betterment of the environment. I think we all agree that we cannot afford to operate in a man–environment manner as we have in the past, that we must evolve new ways of working man into his environment. I think we have, indeed, been developing new approaches. These approaches have been developed by ecologists, biologists, and engineers working together. We have been doing that, for example, in the United States in the area where I work. Specifically our research has also provided to industry and to regulatory agencies specific recommendations which describe the tolerance of biological systems to various changes—to those ends we have developed something we call a thermo-biotic predictive model for esturine systems, and in turn the state in which we work has adopted new regulations that in part reflected the directions where our research suggested. In turn, industry responded to those regulations on the part of the state, and indeed I think are doing a considerably good job in meeting these requirements. So that we are definitely encouraged. Again, getting back to this point of change, Pete Doudoroff mentioned that to be effective as biologists we must be willing to stick our neck out and provide some estimates as to what we think the system can tolerate. I think more and more of us are doing that. I think what we are really striving for is to really get on with the job of managing ourselves. We cannot manage ourselves if we continue under the assumption that we cannot permit any change. There is a poem that I refer to quite often. It goes like this: "The queen bee is a busy soul / she has no time for birth control / and that's why in times like these / there are so many sons-of-bees." The challenge—and I think the queen bee is going to continue to produce. And as long as more people are coming about on the face of the earth, we are going to have to accept environmental changes. The challenge is to manage these environmental changes in a way that is socially acceptable to us.

RICHARDSON: One of the examples of the sort of information or the sort of involvement that M. Dalcq was asking about I think has been manifested in the setting of water quality standards in the United States, a process in which Dr. Tarzwell was very actively involved. I wondered if you would care to comment briefly on the kinds of tradeoffs between science value and politics which were involved in that process? I know this could be the subject of an entire session rather than a brief comment. But I would—and I think others would too—value your brief comments at least on this.

TARZWELL: I shall be glad to do so briefly. In speaking of the work of the committee on Water Quality Criteria for Fish and other Aquatic Life and Wildlife, I have stated that we prepared the report and made our recommendations on the basis of present knowledge, our experience, and our judgment. We found that most of the studies which had been made on temperature, dissolved oxygen, pH and salinity requirements, and on toxicants as a group were short term studies. We had to try to project these into long term effects and levels which would not be harmful under conditions of continuous exposure. We gathered together what data we could on fluctuations in temperature in marine and freshwaters, and we suggested that in the summer period tentatively there might be a rise of 1.5°F; in the winter periods, except in unusual cases, and in the south a rise of 4°F would be permitted; that there should be no heat added to our cold water trout streams and the headwaters of streams where the salmon spawned because so many of them had already been wiped out. We suggested that in the tropics where the organisms were living closer to lethal temperatures, that these increases of 1.5°F should be required over a longer portion of the year. Later we suggested that this should be all year round for the tropics. Then we suggested that due to the differences in

the quality of water in different parts of the country and due to the fact that the quality of a receiving water greatly influences the toxicity of many materials being put into it, that numerical standards could not be given for large areas. We recommended that short term bioassays should be carried out, using for dilution water from the receiving stream taken outside the zone of influence of the effluent in question in order to take cognizance of the materials already in the water. Further, we suggest that the TL50 values determined in our short term bioassays be used with an application factor to indicate—insofar as possible—the concentrations that were considered safe in the receiving water under conditions of continuous exposure. Since only seven application factors had been determined at that time, we suggested that for those materials that hydrolyze and break down rapidly there should be an application factor of 0.1, that is 0.1, the 96 h TL50 or the concentration that killed half the test organisms in our short term 96 hr tests. For those wastes that are broken down by bacteria, we suggested an application factor of 0.05. For materials or wastes that were highly toxic and persistant we suggested an application factor of 0.01, realizing of course for some materials this would be too restrictive and for others not restrictive enough. We had indications that the application factor for cadmium was somewhere between 0.002 and 0.001. But we had to suggest something general. Our recommendations have been used as a basis for setting water quality standards in the United States. Our report was published in 1968—we completed it in 1967. We had only three months to complete the task. The committee was organized on the last day of February and our report was due in mid June. Our committee was composed of 27 people and if you have ever tried to coordinate the discussions of 27 people and get them to agree on things, you know some of the tasks that we had. There is a new report coming out now which they call "The Blue Book"—our report was called "The Green Book." The new report has been under preparation for more than four years. I think it is in publication now. In our report we did try to meet the problems in spite of the lack of data. I think we were quite right in a number of our recommendations and I think they have served to at least maintain environmental conditions that were more desirable for aquatic life. Admittedly, there are mistakes. Admittedly we stuck our necks out and we based our recommendations on available data, our experience, and judgment.

OLLA: I think that we, as biologists, have really not responded to environmental problems in the way we should. The parallel that I can think of has been the concentrated effort on cancer research in the United States for the past two years. The premiss was, if we can go to the moon we can do anything and consequently, if as much money as possible could be devoted to cancer research, this would result in a cancer cure. Of course, at that time, many of the noted cancer research people, attempting to understand the basic workings of the cell, said that an all-out money effort was not the thing needed. Understanding of the basic cell functions is not a parallel situation to shooting a rocket to the moon. While reaching the moon was dependent on technology most of the actual knowledge was already established. The problem of cancer must first be resolved by an understanding of the basic workings of the cell. I draw you back to the environment. We, as biologists, have met this challenge of the environment in a technical way, while what we really require is a basic understanding of the ecosystem. Unless we continue to do this we are not going to solve our problem over the long term.

COOPER: My particular concern here is recycling. I want merely to take up a point which I think has been well made this afternoon: we all need biologists. We need their help, we need their cooperation. One area where I believe we need their help and cooperation is in the field of recycling and waste treatment. We need new processes. We also need new technology. We hope that we have some technology that works. Opinions about that very often differ. What we *do* know is that very often this technology requires fair amounts of energy and quite large metal fabrications to convey materials from one place to another, from one particular stage of process to another. What I think we do not know sufficiently is the extent to which biological processes can be made to work for us, to reduce—quite significantly I suppose—the amount of energy that is required and perhaps to make the systems which must treat the very large volumes of waste we produce operate more efficiently.

GOLTERMAN: I should like to make a comment. We are constantly hearing that we are needing more biologists; in most of the European states at the moment there is unemployment for biologists. Many of the biology students at the moment, i.e. over 50%, cannot get a job. Therefore we turn back to the problem of money. I do not agree with the statement that for biology we do not need all that money—of course we do not need all the money that has been sent to the moon—but, let us say, 1%. That would solve most of our problems.

ROSENTHAL: At one of the first meetings we heard something about the effects of recycling on agriculture. I have yet to hear anything about food production from water at this session. I was wondering when we should hear something about the potential of the oceans and of our rivers and water systems as a source of food for the future.

GOLTERMAN: I think the biologists are very well aware of the problems of farming the ocean. You can only catch fish at certain places where the density is high enough so that you can really catch them. I think that the fertility of the ocean—although it has an enormous potential—at the moment we do not have the technological means of harvesting the material that is growing there.

HEDGPETH: There is considerable optimism and concern about aquaculture, especially fish farming in coastal waters. A lot of us feel that this is perhaps a little rosier than the circumstances would warrant

because of the great expense. We have spent quite a lot of money, for example, trying to raise lobsters. (*Homarus*). The lobster larvae are carnivorous and cannibalistic. So if you want to raise lobsters you have got to separate them as they develop and put them in little individual dishes. The result is that you can indeed raise lobsters but your lobster dinner is going to cost $25 or something in that order at the restaurant at the present rate. There is concern that some people are going a little overboard on aquaculture schemes. Of course there are some reasonably successful enterprises. Some of them being carried out in Puget Sound and some started in Oregon; I am not sure about the latter, as it is in the beginning phases, and it is not certain that it is going to pay out. The main aquacultural resources are in some of the less-developed countries. As is often said, you have a nice cycle there with the family privy emptying into the fish ponds and so on. The considerable quantity of nutrients required to run one of these things is something we tend to forget. With respect to the ocean, I think I ought to point out that our numbering system is a little different. Professor Golterman was referring, I think, to figures that I would call 50 to 90 million metric tons of fishery resources. There are estimates that the populations of krill (*Euphausia superba*) in the Antarctic would yield this tonnage alone. But we are not entirely certain of that now, either, because of the nature of mass populations in the sea and our uncertain data. We have made no basic improvement of practical fishing methods since we came out of the trees, really. It is still a hunt-and-seek procedure and subject to surprisingly great variations. We have lost one major fishery stock in The Pacific Ocean; we may lose the anchovies next, and not entirely through our own fault; perhaps through fluctuations of only one or two degrees a year in the surface temperature of the ocean. Fluctuations on this scale are not uncommon and may be related to oscillations in the global atmospheric system.

PERES: Je pense que l'on peut re'pondre par des chiffres à la question qui a été posée sur la quantité de nourriture que l'homme peut tirer des eaux. Pour les eaux marines, les apports sont d' l'environ 65 millions de tonnes d'apport en poids frais, et, comme l'a dit le Dr. Golterman, ce total comporte environ 25% de poisson à usage industriel. Pour les eaux douces, les apports sont de l'ordre de 8 millions de tonnes exprimés en poids frais. En ce qui concerne l'aquaculture, les apports actuels, chiffrés l'an dernier, à la réunion des spécialistes Fao de Spoleto, à laquelle j'ai participé, se montent à 5,4 millions de tonnes par an environ. Là-dessus l'essentiel —à peu près 5 millions de tonnes—vient des eaux douces. Il y a environ 400 000 tonnes par an de produits marins et d'eau saumâtre. Le programme de la F.A.O. envisage la multiplication par dix des apports globaux de l'aquaculture à l'horizon de l'an 2000, ce qui est probablement faire preuve d'un optimisme exagéré. Les estimations, quant à l'accroissement des captures, sont en général, pour les espèces connues—à condition qu'on en rationalise l'exploitation—et pour les ressources nouvelles, un doublement, c'est-à-dire qu'on pourrait obtenir environ 100 millions de tonnes, à condition que les captures restent dans les normes actuelles de dimension, c'est-à-dire qu'on ne collecte que des animaux marins—la taille, notamment pour les poissons, dépasse 10 cm. Evidemment, si l'on s'engage dans l'exploitation du micronection, les évaluations de production potentielle conduisent à des chiffres qui seraient de l'ordre du milliard de tonnes par an. Seulement, à ce moment-là, se pose un problème d'accessibilité, et on peut craindre qu'on ne dépense, pour capturer ces petites espèces, davantage d'énergie qu'elles n'en fourniraient elles-mêmes. C'est ainsi, je crois, qu'on peut résumer sommairement, en quelques mots, le problème de la production des eaux.

Chapter VII

DESIGN OF GLOBAL SYSTEM MODELS AND THEIR LIMITATIONS

Président: N. N. MOISEEV

CONTENTS

INTRODUCTION

N. N. MOISEEV

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Permettez-moi d'ouvrir notre discussion. Dans notre programme, ce matin, nous allons examiner les problèmes de modélisation. Il me semble logique que ces discussions soient placées à la fin de nos travaux. Dans les discussions précédentes, des aspects spécifiques du problème général de la définition de plans d'actions pour l'humanité ont été examinés. Il est évident que les connaissances profondes des problèmes associés aux ressources minérales l'économie politique, et surtout à l'interaction des ressources énergétiques avec les équilibres thermiques globaux et donc de la stabilité de la biosphère, sont d'une importance cardinale pour la perception des dimensions des problèmes qui nous confrontent. Mais une perspective complète et équilibrée du développement futur de notre planète peut être acquise seulement par une étude simultanée de tous ces domaines. Des possibilités entièrement nouvelles pour de telles études ont été produites par l'existence des ordinateurs modernes et par les disciplines mathématiques qui se rapportent à leur emploi pour de telles recherches. Tel fut le problème qui fut considéré par notre section. Je voudrais souligner que les discussions de notre section ne se rapportaient pas du tout aux questions mathématiques. Aujourd'hui, nous pouvons presque accepter comme axiome que l'impossibilité d'une formalisation complète exprime, non pas les faiblesses des mathématiques, mais la nature même des choses. Il s'ensuit que la transformation des connaissances séparées dans un système de connaissances unifiées, n'est possible qu'en combinant les ordinateurs avec les talents et les intuitions des chercheurs. Cela représente naturellement un problème difficile, sur lequel il existe beaucoup de points de vue, mais après deux jours de discussions, il devient clair qu'en principe nous comprenons tous ces problèmes de la même manière. C'est ce point de vue commun qui vous sera présenté par Monsieur Davous qui fut le Président de notre section. Ensuite, une élaboration de certains points de vue plus spécifiques vous sera présentée par Messieurs Forrester Mesarovic, et moi-même, si vous le permettez. Ensuite nous ouvrirs la discussion générale dans laguelle Messieurs Kalmann et Matsuda auront l'opportunité de nous communiquer ce qu'ils pensent à ce sujet.

Je donne la parole à Monsieur Davous.

RAPPORT DU GROUPE SUR LA MODÉLISATION DES SYSTÈMES MONDIAUX ET SES LIMITES

P. DAVOUS

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L'organisation du présent rapport ne suit pas exactement l'ordre chronologique des débats, car des préoccupations voisines sont souvent apparues dans les communications placées à différents moments de nos séances de travail. En outre, plusieurs de mes collègues m'ont suggéré de commencer ce rapport par un bref rappel de ce qu'est la modélisation, bien que nous n'ayons pas, en séance, attaqué le problème de définir exactement le terme de "modélisation".

Donc, après ce bref rappel sur la modélisation en général, nous ferons, dans une seconde partie, une revue de divers domaines où la modélisation a été déjà employée avec un niveau de succès variable, en essayant bien entendu de tirer un enseignement de cette analyse, c'est-à-dire, de corréler le niveau de succès avec certaines caractéristiques des problèmes attaqués par le modélisateur.

Dans une troisième partie, nous aborderons l'examen des modèles mondiaux actuellement proposés; nous avons eu la chance dans ce congrès de voir participer à ces travaux les leaders les plus éminents des groupes de modélisation mondiale, et mon seul regret est que la brièveté des discussions, due à un nombre de conférences peut-être trop élevé pour deux courtes journées de travail, n'ait pas permis de développer aussi loin qu'il aurait été souhaitable les échanges de vue entre ces personnalités de premier plan.

Dans une quatrième poirite, nous nous placerons à la pointe des recherches actuelles; là aussi, grâce à la présence des meilleurs spécialistes, nous avons pu voir s'entrouvrir les voies d'évolution des techniques de modélisation, tant dans le domaine des outils théoriques de base (mathématiques) que dans le domaine de la sociologie de l'action.

A la fin de ce rapport, je vous donnerai lecture des résolutions proposées par le groupe de travail.

Je voudrais remercier ici tous les membres du groupe de travail pour l'aide qu'ils ont apporté au rapporteur dans la rédaction des résolutions, et aussi tout spécialement les orateurs, et les quatre présidents de séance: Messieurs Forrester, Moiseev, Matsuda, et Michiels.

1. LA MODÉLISATION

Pour donner un contenu au terme de modélisation, nous prendrons tout simplement comme point de départ la définition que le dictionnaire donne du terme "modèle": "le

modèle est une représentation schématique d'un objet ou d'un processus qui permet de substituer un système plus simple au système naturel".

Un modèle c'est donc un substitut d'un objet réel ou d'un processus réel.

A quoi peut donc bien servir un modèle? C'est un outil pour augmenter notre connaissance sur l'objet imité ou pour transmettre de l'information sur cet objet. Un modèle peut être utilisé à la place de l'objet ou du processus qu'il représente soit pour des raisons d'économie (cela coûte moins cher d'extraire de la connaissance du modèle) ou de disponibilité (le modèle peut représenter un système qui n'existe pas encore, ou un système que l'on ne peut pas manipuler pour des raisons de taille ou de danger . . .).

Et il y a bien des milliers d'années que les hommes se sont servis de modèles, au moins dans les sciences de la nature: astronomie, physique, biologie. Dans les sciences humaines, l'apparition de modèles est peut être plus récente, encore que l'on puisse remonter au XVIIIème siècle avec les travaux de Buffon sur l'arithmétique morale et de Condorcet sur la décision des assemblées.

Ne concluons cependant pas trop vite qu'il n'y a rien de nouveau sous le soleil: l'époque moderne apporte la conjonction d'outils mathématiques adaptés à la description des systèmes dynamiques complexes, et d'outils technologiques (les ordinateurs) capables de manipuler les algorithmes mathématiques de description des systèmes. Ceci étend de façon formidable le champ ouvert à la modélisation car ce fameux substitut de l'objet réel est un simple programme d'ordinateur, et il n'y a pas à fabriquer, à usiner un objet matériel spécifique imitant l'objet réel.

Il convient cependant de tempérer notre enthousiasme:

D'abord, il n'est pas si "simple" de réaliser un programme d'ordinateur.

Ensuite, le fait même que nous manipulons un substitut abstrait de l'objet ou du processus réel ouvre la porte à toute sorte de difficultés dont la principale est la difficulté pour le non-spécialiste de comprendre ce qu'il y a dans la boîte noire, d'avoir une vision immédiate et synthétique du phénomène.

Une autre difficulté est que le fait d'avoir certains outils de modélisation, certains formalismes, n'implique pas que tous les phénomènes réels observables vont avoir le bon goût de subir légitimement cette formalisation.

Enfin, il est bon de rappeler qu'un modèle donné ne peut pas être d'une généralité telle qu'il permette d'étudier n'importe quelle caractéristique de l'objet imité. Il a toujours l'objectif limité de répondre à une question ou à un groupe de questions que l'on se pose sur l'objet réel.

Une modélisation bien conduite doit donc suivre certaines étapes:

Bien formuler le problème que l'on cherche à résoudre à propos du système réel.

Rechercher une formulation mathématique décrivant le système réel. Lors de cette formulation, bien expliciter les hypothèses simplificatrices faites.

Ecrire un programme d'ordinateur traduisant cette formulation mathématique ou algorithmique (certains langages généraux adaptés à décrire d'assez larges classes de systèmes mathématiques peuvent faciliter cette tâche—langages Simscript, GPSS, Dynamo, Simulates . . .—).

Faire fonctionner ce programme à partir de données issues d'analyses statistiques faites sur le système réel.

Valider le modèle, c'est-à-dire vérifier que les résultats donnés par le modèle coïncident avec des données relevées sur le système réel; cette tâche en apparence simple est en réalité très complexe, car les données historiques relevées sur le système ont peut-être justement

servi à établir certains coefficients du modèle; un test meilleur est bien sûr de vérifier si le comportement futur du système réel est conforme à ce qu'a prédit le modèle. Mais le problème est encore plus complexe et sa discussion nous emmènerait trop loin.
Enfin, après validation du modèle, on entre dans l'étape d'exploitation du modèle qui est loin d'être simple: il faut construire de véritables plans d'expérience pour choisir de façon optimale les groupes de données de départ utilisées pour obtenir les réponses aux questions que l'on se pose au sujet du système réel.
Quand le système réel est un système dont la structure ou les caractéristiques évoluent dans le temps, le modèle devra évoluer lui aussi et vivre pour refléter ces changements structurels.

2. ETAT ACTUEL DE LA MODÉLISATION

Nous allons maintenant survoler rapidement quelques domaines d'application de la modélisation, en insistant spécialement sur le niveau de succès ou d'échec rencontré par les modèles. Nous laissons pour la troisième partie les modèles mondiaux.

2.1. Quelques données numériques

Je commencerai par rappeler quelques données numériques fort intéressantes données par le Professeur Shubik sur les dépenses occasionnées par les activités de modélisation aux Etats-Unis.

450 modèles militaires ont été identifiés par un groupe composé du Prof. Shubik et de Garry Brewer; plus de 130 ont été analysés en détail.

Un autre groupe a identifié 1140 modèles civils et 300 ont été analysés en détail.

Le coût moyen est de $250 000 pour les modèles militaires, de $140 000 pour les modèles civils qui sont construits autour d'un nombre plus restreint d'équations, environ 25.

Les dépenses totales sont de l'ordre de 100 millions de dollars par an.

Chaque modèle utilise en moyenne 4 hommes-années et entre en service environ 17 mois après le début de l'étude.

Les buts poursuivis par ces modèles sont multiples:

52% visent à aider le choix de politiques
53% traitent de l'analyse d'un problème
43% traitent d'évaluation de système
48% servent à la prévision

Le total de ces chiffres fait plus que 100% car chaque modèle peut avoir plusieurs buts.

2.2. Domaines de succès des modèles

La notion de succès d'un modèle est évidemment très subjective: à l' extrême on peut dire qu'il y a succès si le modèle a une validité démontrée scientifiquement et s'il est effectivement utilisé; mais on pourra hélas aussi définir le succès par le fait que la personne qui a financé le modèle est contente du résultat.

Néanmoins, on peut dire en gros que le succès dépend du domaine d'application et de la façon dont le modèle a été construit.

Le succès est plus fréquent si le système étudié, tout en étant relativement complexe, est lié à ce que l'on pourrait appeler des "déterminismes forts". Ce sera le cas de beaucoup de systèmes physiques, ce sera le cas aussi des modèles servant à définir une politique optimale d'affectation de moyens bien définis à des tâchesb ien définies, en présence de contraintes bien définies, comme c'est le cas de ce que l'on appelle la "programmation linéaire" ou son extension, la "programmation mathématique".

C'est le cas enfin pour quelques modèles de prévision économique à court terme, et en l'absence d'éléments majeurs imprévisibles.

Nous avons dit aussi que le succès dépend de la façon dont le modèle a vu le jour; nous aurons l'occasion de revenir sur ce point important, mais notons dès maintenant que si l'homme qui finance le modèle a une vision tres claire de la question à laquelle il souhaite voir apporter une réponse, et s'il contrôle lui-même les phases d'exécution du modèle, les chances de succès seront plus grandes.

Au cours de nos séances de travail, plusieurs exposés ont traité de ces types de modèles.

Monsieur Åström a présenté les différents types de problème rencontrés dans la modélisation des systèmes de contrôle industriel et d'optimisation. Le Professeur Medow a présenté une communication du Professeur Khachaturov sur un système de simulation pour le développement d'un centre de production de gaz et de pétrole.

Dans un domaine un peu différent, l'application de la modélisation aux problèmes écologiques a été présentée par le Professeur Moiseev d'après les travaux du Professeur Sverezhev. Cette communication présente, dans une vision large et ambitieuse, l'orientation de l'école soviétique dans le domaine des études systématiques de la biosphère.

Dans le domaine économique, le Professeur Ivanov nous a expliqué comment les techniques de modélisation s'appliquaient assez bien à la gestion d'une économie socialiste centralisée.

Enfin, Monsieur Vatel nous a montré comment l'on pouvait concevoir une procédure itérative pour la préparation des décisions sur la protection de l'environnement (en introduisant pour chaque notion un facteur de préférence entre la satisfaction des objectifs nationaux et la satisfaction des objectifs mondiaux).

2.3. Causes d'échec en modélisation

De très nombreuses causes ont été mentionnées au cours des travaux; elles se groupent en quelques classes:

— Non-reconnaissance de toutes les dimensions du système étudié. Par exemple on ne traite que la partie physique d'un système sans tenir compte des dimensions socio-économiques. C'est le danger "réductionniste". Monsieur Brockett a axé sa communication sur ce point, en notant que les systèmes humains changent leur comportement justement à la suite d'une modélisation qui les concerne.

— Mauvaise définition des frontières du système et oubli de certains facteurs d'influence importants.

— Simplification abusive de la description du système: on fait certaines hypothèses qui permettent de traiter le problème, mais le modèle cesse d'être pertinent.

— Le danger inverse est également présent: on peut très bien construire un modèle abusivement complexe. Si les données disponibles ne sont pas suffisamment précises et certaines, si elles sont entachées d'erreurs de mesure, il est illégitime d'inclure dans

la description des degrés de liberté supplémentaires qui détériorent le modèle plutôt que de l'améliorer. Un exemple de ce phénomène a été décrit par le Professeur Akaike: il y a un niveau optimal de complexité du modèle.

— De nombreuses causes d'échec sont à rechercher dans la mauvaise prise en compte de paramètres sociologiques et psychologiques présents dans le travail de modélisation même:

. on fait par exemple un modèle sans client pour le modèle, c'est-à-dire sans personne capable de définir précisément ce que l'on attend de ce modèle.

. ou encore l'interaction entre tous les acteurs économiques intéressés par l'activité de modélisation n'est pas correctement établie et entretenue. Plusieurs communications ont insisté sur ce point.

Le Professeur Shubik s'est livré à une analyse taxonomique de ces acteurs: politiciens, dirigeants, groupes de planification, professeurs et aussi le public dans certains cas. Tous ces acteurs poursuivent des buts différents, ont des perceptions, des responsabilités, des intérêts différents. Monsieur Brewer a montré les déviations qui peuvent résulter de certains intérêts personnels. Monsieur Friedmann a insisté sur la nécessité d'inclure dans le processus de planification les acteurs qui ont la perception la plus claire de la situation, et d'éviter tout élitisme. Monsieur Cornblit a insisté dans le même sens.

La nécessité d'arriver à un modèle compréhensible par les utilisateurs a été soulignée par Monsieur Michiels.

Tout le problème des communications à assurer autour de l'activité de modèlisation a été évoquée à plusieurs reprises.

Il a été mentionné que les documents décrivant les modèles étaient souvent si mal faits ou même inexistants que seul le rédacteur du modèle pouvait le modifier ou même simplement l'utiliser.

Il faut sans doute voir là des imperfections de jeunesse, mais il faut bien les identifier et les corriger.

3. LES MODÉLES MONDIAUX ACTUELS

Il est temps de passer maintenant à la présentation des modèles mondiaux. Comme je l'ai déjà mentionné, nous avons eu la chance d'avoir à notre groupe de travail des leaders des groupes de modélisation mondiale les plus éminents.

Je vais présenter brièvement les caractéristiques de quatre modèles qui sont bien représentatifs de l'état actuel de la modélisation mondiale: le modèle du Professeur Forrester et du Professeur Meadows, le modèle des Professeurs Mesarovic et Pestel; le modèle de la Banque Mondiale présenté par le Professeur Chenery, le modèle présenté par le Professeur Moiseev.

L'analyse qui va suivre est due à l'amabilité de Monsieur Richardson qui m'a aidé dans la préparation de cette partie du rapport.

3.1. Le modèle Forrester–Meadows

Popularisé par son application décrite dans le best-seller "the limits to growth" ou "Halte à la croissance" pour l'édition française, ce modèle s'appuie sur la méthodologie de dynamique des systèmes développée par le Professeur Forrester.

— Le niveau géographique d'analyse est le monde pris globalement.
— L'horizon temporel dépasse 100 ans.
— Le point de vue principal adopté est la définition des limites à la croissance.
— Les données de base sont relativement agrégées et donc en nombre assez limité.

Le modèle étudie l'interaction de cinq variables principales: population, superficie cultivée, capital agricole, capital industriel et pollution.

Je pense que le Professeur Forrester fera lui-même un commentaire sur la signification à apporter aux résultats de ce modèle, sur l'importance qu'il accorde à la validation du modèle par le public, et sur la nécessité d'élargir les horizons de la modélisation en la couplant mieux avec les besoins du public.

3.2. Le modèle Mesarovic-Pestel

La méthodologie utilisée est une simulation de systèmes hiérarchisés complexes à plusieurs niveaux.

Plusieurs niveaux ou strates sont définis:

. niveau des individus, des groupes
. niveau démographique et économique
. niveau technologique
. niveau écologique
. niveau géophysique

Les couplages entre ces différentes strates sont explicités. Outre les relations causales, les aspects sociologiques sont pris en compte par des scénarii.

Le couplage avec les processus de prise de décision, de formulation des normes est également introduit. La prise en compte de ces différents couplages aboutit à un système d'un millier d'équations.

Le monde est divisé en 10 régions.

L'horizon temporel est 50 ans.

L'étude est centrée sur les variations cycliques affectant la population, les ressources alimentaires, énergétiques, minérales et l'apparition de crises.

Les données introduites sont abondantes sur les ressources agricoles, énergétiques, les superficies utilisables, les facteurs économiques principaux.

Je laisserai là aussi le soin au Professeur Mesarovic de vous exprimer ce que sont les résultats de ce modèle et les recommandations qu'il en déduit, notamment sur la nécessité d'une coopération internationale.

3.3. Le modèle Chenery – Banque Mondiale

La méthodologie utilisée est l'analyse économique s'appuyant sur des matrices d'échange entre nations (de 16 à 18 lignes et colonnes).

Le monde est étudié au niveau des nations.

L'horizon temporel est de 10 à 15 ans.

L'orientation principale du modèle est l'étude de la distribution des ressources et le développement économique des nations dans un contexte global.

Les données utilisées sont extrêmement abondantes, la base des données est probablement la plus volumineuse des quatre modèles étudiés.

A partir d'hypothèses sur l'évolution de certaines variables, prix et politiques, des simulations globales sont effectuées aboutissant à certains scénarii.

Les résultats de ces scénarii servent à orienter les redistributions de financements de la Banque Mondiale entre les nations.

3.4. Le modèle Moiseev

La méthodologie utilisée diffère des précédentes: dans la description des phénomènes, on s'efforce de faire apparaître des invariants auxquels on pourrait appliquer un principe de conservation.

Le monde est divisé en une dizaine de régions.

L'accent est mis plus sur les problèmes de perturbations globales techniques que sur les phénomènes démographiques.

Le système de modèles est directement contrôlable, c'est-à-dire qu'il contient des paramètres et des fonctions libres, représentant ses instruments de contrôle, (qui peuvent être changés par des procédures d'optimisation ainsi que par des procédures de simulation).

Le modèle de production contient cinq secteurs: moyens de production, biens de consommation (sauf alimentation), agriculture, matières premières et énergie.

Le progrès technologique est inclus dans le modèle. Le Professeur Moiseev vous parlera je pense, des résultats actuels acquis.

3.5. Evaluation de la situation actuelle de la modélisation mondiale

La première remarque est qu'il y a en fait deux audiences bien distinctes pour de tels modéles: le public et les décideurs. Suivant que l'on cherche à atteindre une sensibilisation de l'opinion ou au contraire d'apporter aux décideurs certaines perspectives sur les conséquences possibles de leur décision, on aboutit à des modèles qui différeront par plusieurs points:

— par la nature des problèmes couverts d'abord;
— par la nature du modèle lui-même;
— par les critères de validité.

Les deux types d'activité de modélisation sont légitimes; encore convient-il que les modélisateurs expriment clairement quelle audience ils visent et quel est leur but.

Les conclusions que l'on peut tirer des modèles globaux existants contiennent des éléments factuels, mais aussi des éléments subjectifs liés à une certaine vision du modélisateur et à son système de valeur. Les travaux disponibles actuellement ne mettent peut-être pas suffisamment en lumière ces deux classes d'éléments. Ils ne sont pas assez explicites sur le degré de certitude que l'on doit attacher aux prévisions et aux conclusions.

Les modèles qui visent à influer sur des décisions de changement d'orientation, de définition de politiques, utilisent à l'heure actuelle des données nationales, alors que les problèmes analysés sont justiciables d'une analyse globale.

Il est clair qu'une coopération accrue entre les équipes travaillant sur les modèles globaux est souhaitable, mais la diversité de ces efforts amène à penser que cela sera difficile à réaliser à court terme.

C'est cependant vers une telle coopération que la plupart des équipes impliquées dans la réalisation de modèles mondiaux voudraient aller; bien plus, une insistance toute particulière a été mise sur l'urgence de décisions à prendre dans ce sens.

Nous aurons à revenir sur ce point dans la présentation des résolutions du groupe de travail.

4. VOIES DE RECHERCHE AVANCÉE ET POINTS DE CONTROVERSE EN MODÉLISATION

Il convient maintenant de parler des voies de recherche avancée en modélisation.

Des progrès rapides ont été effectués au cours des dix dernières années. Le Professeur Kalman nous a montré comment les concepts issus de la théorie des systèmes apportaient des outils d'attaque pour la modélisation des systèmes dynamiques complexes. (Il nous a montré le danger qu'il y aurait à croire que certains concepts appartiennent à des domaines spécialisés alors qu'ils sont de nature purement mathématique; dans le domaine de l'économie par exemple, il serait dangereux d'interpréter le concept de programmation linéaire en termes de superstructures économiques.)

Puis le Professeur Kalman a montré comment la théorie de la réalisation des systèmes linéaires permettait de jeter les bases d'une théorie de la modélisation. (Un résultat intéressant de cette approche est de montrer l'existence d'une correspondance entre la description d'un système en termes de comportement et sa description en termes de structure, réduisant ainsi à un problème vide la querelle entre les béhavioristes et les réductionnistes.)

Tout cela est prometteur et les travaux de ce genre doivent contineur, mais il est à observer que leur utilisation directe dans les problèmes de modélisation globale n'a pas été réalisée à ce jour.

Le Professeur Marney a abordé sous un angle assez différent les problèmes de modélisation: il nous a donné les premiers éléments d'une réflexion sur la modélisation des systèmes adaptifs en utilisant une approche qu'il appelle "approche théorique normative".

Il étudie le contexte stratégique dans lequel s'inscrit l'action de modélisation, note la sensibilité des décisions aux normes et se livre à une critique approfondie de ce que nous appelons "rationalité" quand nous parlons de systèmes globaux. Il propose une organisation du domaine de la décision en plusieurs niveaux couplés en une structure hiérarchique. Deux prototypes de tels systèmes de décision ont été évoqués.

Plusieurs autres exposés (notamment ceux de MM. Matsuda et Dalkey) ont insisté sur le problème des valeurs et sur la manière d'introduire dans les activités de modélisation une prise en compte efficace du système de valeurs du groupe social concerné.

Pour définir correctement les buts d'une organisation, le Professeur Matsuda insiste sur la nécessité de fournir à toutes les parties concernées les informations pertinentes sur les conséquences prévues des actions et d'organiser la résolution des conflits.

Le Professeur Dalkey a proposé une approche permettant d'accéder aux valeurs humaines de référence privilégiées par un groupe.

Nous arrivons maintenant à un point très fondamental: plusieurs orateurs ont posé la question de la justification même des activités de modélisation.

Le Professeur Churchman a proposé de remonter à une approche donnant plus de poids à la tradition humaniste si nous voulons aboutir à un monde adapté aux exigences fondamentales de l'humanité.

Il indique comme voie essentielle de recherche un approfondissement de notre connaissance de l'homme comme créature biologique, psychologique, sociologique, morale, mythique.

Le Professeur Ansoff, étudiant l'état de nos connaissances sur le comportement des organisations, a tracé une fresque de l'évolution des approches utilisées depuis une vingtaine d'années pour formuler la stratégie des groupes humains. Il a montré comment ces approches se sont enrichies progressivement, passant de l'organisation élémentaire des tâches à l'identification des variables stratégiques, puis incorporant les problèmes de management des discontinuités, des crises, et débouchant sur une théorie du comportement stratégique.

Le Professeur Ansoff insiste pour que nous allions au-delà des approches cartésiennes et que nous attaquions l'action en matière de processus sociaux comme un tout, dont la rationalité n'est pas restreinte aux activités de modélisation.

Je rappelle enfin la position déjà citée du Professeur Shubik, car son souci de voir exister un système efficace de construction des institutions se rapproche des préoccupations ci-dessus. Je citerai seulement une de ses phrases qui me paraît un excellent condensé de sa position: "Essayez-vous de résoudre un problème, ou êtes-vous une partie de ce problème?"

Monsieur Harman a soulevé la difficulté suivante: les problèmes que nous rencontrons ont été en fait créés par le succès de l'ère industrielle. Il se peut que nous soyons à un point où les modes de pensée issus de l'ère industrielle ne s'appliquent absolument plus et que nous devions passer à une vision radicalement nouvelle de la société post-industrielle. Si c'est le cas, les modèles actuels issus de modes de pensée anciens doivent être utilisés avec la plus extrême prudence.

Certains de ces points de controverse s'exprimeront sans doute au cours des débats, mais peut-être trouvent-ils un début de solution dans la synthèse ambitieuse présentée par le Professeur Jantsch. Il est sans doute encore plus ambitieux d'essayer de la résumer en deux phrases mais au risque de déformer la pensée du Professeur Jantsch, j'indiquerai qu'elle consiste à classer les systèmes suivant deux dimensions:

- la première dimension est liée au type d'interaction entre l'observateur et le système; ils sont ou totalement distincts, ou en interaction dialectique ou enfin, au troisième niveau, l'observateur fait partie du système.
- La deuxième dimension est liée au degré de conscience du système. Le premier niveau correspond à la dimension physique, le deuxième à la dimension biologique, le troisième à la dimension humaine.

Croisant ces deux dimensions, le Professeur Jantsch définit ainsi neuf domaines différents pour chacun desquels la notion de modèle prend un sens différent et la nature des problèmes posés va depuis les niveaux les plus simples (causalité de type mécaniste) jusqu'aux plus complexes (genèse des systèmes culturels).

La dernière conférence présentée a été celle du Professeur Medow qui a proposé une méthode d'attaque des problèmes de modélisation mondiale, faisant un large appel au couplage interactif entre l'homme et l'ordinateur. Trois individus ou groupes d'individus travailleraient dans trois salles équipées de terminaux d'ordinateurs, de moyens de visualisation et de communication.

Le premier groupe définirait les situations nécessitant action et les spécifications des programmes à développer pour maîtriser ces situations.

Le deuxième groupe serait chargé de la tâche de réaliser ces programmes.

Le troisième groupe prendrait en compte les conditions de stabilité biologique et sociale.

Un quatrième système de supervision assurerait la régulation d'ensemble de ces interactions à partir d'un algorithme de planification.

Dans la discussion qui a clôturé nos travaux un certain nombre de points susceptibles de donner lieu à des recommandations ont été évoqués.

Les résolutions qui vous seront lues tout à l'heure essaient de dégager une position commune; mais il est clair que ces résolutions ne sont pas l'expression d'une position unanime du groupe.

Il est donc souhaitable qu'au cours des discussions de cette matinée, des points de vue complémentaires puissent s'exprimer.

DISCUSSION

MOISEEV: Merci Monsieur Davous pour votre très grand travail.

FORRESTER: We must recognize that all operating decisions and all political decisions are now made on the basis of models. The mental images we use in our decision making are models. One does not have a country, or a city, or a world in his head, but only assumptions about the structure and the nature of those systems. We do not have the option of not using models, because everything we do is already based on some model. So we should address ourselves to how models should be improved. One can approach modeling from various directions—from statistical information, from theory, or from mathematical technique. But one can also approach from a different direction. One can approach modeling from that body of descriptive knowledge we are now using in our private and political decisions. One can take descriptive knowledge and cast it into a more formal and orderly form. We have available a wealth of information. In fact, we are overwhelmed by information. We are handicapped less by a lack of information than by having too much information. On the other hand, that information is fragmentary. It is not well organized. The statements are usually imprecise. We do not have effective ability to determine the future implications of the assumptions that we are willing to accept. In other words our present assumptions might lead to future consequences quite different from those we expect. It is possible to take any kind of verbal description and cast it into a formal model structure that represents the rates of flow and the accumulations of both the tangible and intangible variables. One can organize a model that cuts across disciplines to include psychological, economic, monetary, and physical variables in one unified structure. By doing so, one can locate the internal contradictions in the information we are now using, find the future consequences of assumptions we are now accepting, and determine alternative future behavior that would follow from different policies. Such a model communicates with the descriptive knowledge in the operating world. It communicates with political and business leaders and with the public. I believe the branch of modeling that starts from descriptive information about the operating world will yield the greatest payoff for least effort.

OALKEY: Professor Forrester has made the important point that we cannot avoid using models—any decision is made in light of our understanding of the world, which is in a sense a model. I also agree with Professors Churchman and Shubik that the models we have in our minds are not the same sort of thing as the kind of models that can be represented by computer programs. Our mental models are intuitive, fuzzy, and incomplete. In addition, mental models differ widely from individual to individual. The differences can be very large even for individuals in the same professional community.

In this situation there are two approaches that can be taken. One is the traditional route where a creative individual formulates his model in greater specificity, perhaps with the help of other individuals. It is then possible to include knowledge and insights of others in terms of judgmental inputs.

A different route is to try to include the knowledge of all members of a group by creating a group or collective model, that is, a model which aggregates the individual models. Methods for doing this are in an early stage of development at present. Some help can be obtained from dimension—reduction techniques such as factor analysis, chester analysis, and multiple dimensional scaling. By such techniques it is possible to reduce the large, miscellaneous set of elements or factors included in the individual models to a small, coherent, list of factors.

Similar techniques can be used to formulate collective value judgments, sets of priorities, and the like.

Although methods for generating collective models are in an early stage of development, they are researchable, and progress is being made in making them available for policy assessments.

MESAROVIC: I cannot describe the model which we have developed in our group. Before talking about the results let me just state again briefly our motivation. Our main goal was not to develop a model to predict the future development of the world system which we do not believe to be possible, but rather to develop a planning tool, that is a flexible procedure for the assessment of the alternative parts of development which, of course, is based on a certain model. The model is part of a procedure for the assessment of the parts of alternative parts of development rather than to predict the future. Our immediate objective for the first variation of such a tool or of such a model as a part of this tool was designed, was the assessment of the alternative ways in which we could solve the world crisis. How could it be solved? We referred to a particular economic gap, food, energy crisis, and so on. I mentioned the economic gap or inequality in the world first as I did in my presentation to the group because we considered that to be problem number 1. That, of course, is reflected in the structure of the model as we developed it. We have asked some specific questions we wanted to analyze by using the tool because the model and the tool was, of course, designed to answer some of these questions. We were particularly interested in the following four questions. They are more or less obvious but there are some others which can be added which we have not considered. Question 1 is: These crises are persistent, that is, are they going to get better or worse and in what sort of ways and in what magnitudes and so on? Question 2: Whether they can be solved in national or regional boundaries, as we, of course, perceive them: or are the solutions possible only within a global context? Question 3: Whether they can be solved by traditional means, and what we mean by traditional means if, of course, to explain the scenarios as we play them enough? Question 4: Is the confrontation the only way

to solve the problem of whether there is a rational process for cooperation? I say confrontation because there are several ways in which the world crisis can be solved which we do not have to elaborate on here but which do not require necessarily cooperation. Cooperation is not the *only* solution. But the question is whether it is a rational enough solution. So these were the four questions which we tried to answer, using our tools in reference to the crisis I mentioned. Let me just give you the answers we arrived at and then let me briefly describe the scenarios which led us to provide these answers. To question 1: The crises are indeed persistent. In our assessment, they are going to get worse before they get better. Question 2: Whether they can be solved in national, regional boundaries—particularly the food crisis, which I feel was not emphasized enough, at least according to my own feelings at this meeting, cannot be solved within regional boundaries. I do not mean only in terms of physical, productional food, but also economic and so on. So a global context is needed. Question 3: Whether traditional measures are sufficient or not; the answer is again no. And we will elaborate on this later on, but it boils down to the fact that we cannot talk about demographic problems only, nor can we talk about economic development problems only, nor can we talk about the energy crisis only, but they are so coupled that we have to look into ways how to solve all of them simultaneously. Question 4: Whether cooperation is possible, whether there exists a rational basis in which no participants so to speak are losing so much as to be able not to cooperate. The answer to this question from our viewpoint is yes. There exists a basis. Again, this is based on our assumption model which is available for consideration. Again, I am not saying that that is the future and I am not saying that that is the only solution, I am just saying that this is *a* solution according to our analysis. Now let me just give you some of the scenario for a solution to the world food crisis. We have played hundreds of different scenarios, but let me give you five cornerpoints, if you like, to show you how we arrived at the conclusions I have just mentioned. Let me refer to the food situation in south and southeast Asia. As you all know, according to a United Nations estimate there will be an additional 1 billion people in south and southeast Asia—whether it will be by the year 2000 or the year 2005 or 2010 is an open question. But it will be there. So we have to worry about an additional billion people in that region. Number 2: looking at the maximum arable land available, that translates into a 200-250 people per square kilometer of arable land. That is just to show you the magnitude of the problem which we are confronted with. So Scenario number 1 is a historical pattern of development as we understood it on the basis of our data and so on, and whether the problem could be solved. The answer is no. Let me not go into details. It is not only an economical question: according to our assessment it is a physical question as well—not only producing food there but importing food from outside. Scenario number 1 is based on food being available from outside in the form of aid so that there is no slowdown of population momentum. This is clearly not a feasible scenario, but it is a scenario. So in that way a solution cannot be found. Scenario number 2, which we call a tragic scenario, is that food is not available and therefore the population will slow down according to a shortage of protein and so on, and that, of course, does not represent a solution in any way whatsoever. Scenario number 3, self-sufficiency, regional self-sufficiency, that is shift of investment from industrial development to agricultural development regionally, to the maximum possible extent. According to our assessment, it indicates that the industrial development will be hurt so much that it will simply not provide a solution in the sense that the food will be continuously needed to be imported into the region. Scenario number 4, in which our national cultural investment and aid is provided to the region, again turned out to be unsatisfactory because there will still be a large portion of economic output of gross regional product needed to pay for this aid which is strictly agricultural. This industrial agricultural aid is based not only from, say, some of the developed world but provided on a global basis because the economic load would be too much to bear. So that is the fifth scenario which, according to our analysis, could provide a solution. Will that happen? I do not know. There are many other alternative ways. But that is a solution. So this type of scenario analysis and these five scenarios, particularly in the food crisis situation, led us to pose the question as previously mentioned. It was on a still higher level that led us to the concept of organic growth as a contribution to the growth discussion right now, that is the pro-growth or zero-growth dilemma.

In conclusion let me just say that we held a five-day seminar at the International Institute for Applied Systems Analysis in Luxembourg and the proceedings—about 3000 pages—describe all the data and all the equations and have papers from about fifty people which are available for inspection. The general results, which I have just indicated, together with the concept of organic growth which we think is important as a vision of where do we go from here, will be available in a book entitled *Mankind at the Turning Point.*

MOISEEV: Maintenant je donne la parole à M. Chenery.

CHENERY: I am not prepared for any extensive comment, but I will give a brief summary of the models that have been discussed. The World Bank model is the only one which has been designed for specific operating decisions in a short time-frame. Our problem was essentially: What is the minimum amount of modeling needed in order to analyze the current oil-raw materials crisis, and the role of aid in that? I think we started from the other end than the two that have been described, essentially taking models of the developing countries and linking them to models of the advanced countries, in a minimal way. We do not try to explain everything that is happening but rather to identify the most important linkages between the developing countries, the oil countries, and the advanced countries of Europe. I think rather than describe the structure of the model, perhaps two or three examples of the kind of conclusions which are

not obvious may be of interest. I personally think that some of the approaches to modeling which start with a very general formulation make the crisis seem unnecessarily complex or unnecessarily connected, so that we tend to think that each crisis reacts on the other. On the other hand, in this particular one, I am afraid that there are at least three interactions which have to be taken into account. If we take India—which Mr. Mesarovic was just talking about—as the *locus classicus* of the problem, first, the price of oil goes up, as it has, by four times, the impact on India's balance of payments is an increased cost of $800 million in the first year and then it goes up and competes with food and fertilizers. Without relaxing any of the constraints on the problem, the supply of fertilizers is then inadequate to produce food, so that food production is actually reduced because of the necessity of paying for oil. Our model essentially traces this kind of interaction through the balance of payments of all major countries, and tries to identify the kinds of things the world can do about it. I think the most simple and obvious result is not that the price of oil should come down, which I think is unlikely, but rather that the countries that are benefiting from the oil profits should in some way favor the poor countries, which is not happening to any large extent. So I would say that the contribution of models of the form that we have developed shows the possibilities of a combination of policies in which everybody benefits and the losers are compensated somewhat in the classical way. The amount required to compensate the losers by the people who are gaining is rather small. It could easily be lost in a global model but unfortunately it affects something like one billion people, although it is only several billion dollars out of an increase of oil revenues of 80 to 100 billion dollars. But the focus on the alternative ways probably is the main contribution which this particular exercise brought out.

MOISEEV: Et maintenant je vais donner la parole à moi-même. Je ne veux pas répéter les principes sur lesquels notre travail est basé. Ceci sera publié. Je vais donc livrer brièvement certains commentaires sur notre travail, et sur ses buts. Je pense que la complexité de problèmes que nous confronton est la cause principale de nos décisions d'accord, sur le point que le développement et l'application des méthodes d'études modernes basées sur les procédures homme-machine sont absolument nécessaires. Je dirai même plus. Il n'existe pas d'autre alternative pour l'étude de problèmes interdisciplinaires d'une certaine complexité. Le point sur lequel certains d'entre nous diffèrent concerne les méthodes selon lesquelles les modèles doivent être construits, le rôle de certains processus écologiques, sociaux, etc. Il nous semble qu'aujourd'hui, à époque actuelle, il faut concentrer nos efforts, non pas sur la formulation rapide de quelques recommandations pratiques, mais sur la réalisation d'un certain programme d'ordre scientifique. La possibilité, dans les années qui vont suivre, d'une dissémination prématurée des conclusions superficielles, associées avec des méthodes, représente un très grand danger pour la réputation de la science dans ce domaine. Un tel programme scientifique doit incorporer non seulement des modèles de la biosphère, des balances thermiques de la planète, etc., mais aussi les processus qui ont lieu dans la sphère économique. Malheureusement, il faut reconnaître que les méthodes de la science économique traditionnelle ne nous fournissent pas tous les éléments qui sont nécessaires à la construction d'un tel système de modèles, c'est-à-dire d'un système des modèles qui permettrait éventuellement d'arriver à des conclusions pratiques à l'échelle mondiale. Ces études doivent être liées aux expériences qui ont déjà eu lieu, comme par exemple Cellis de Forrester et Mesarovic. Je pense qu'un tel programme doit servir de base pour les activités futures de notre groupe de Paris, qui est né d'une façon naturelle dans le cadre des travaux de notre conférence. C'est grâce aux efforts de Monsieur Marois et de ses collègues que cette association non formelle d'hommes de sciences est venue en vie. Il n'est pas possible, à l'étape actuelle, de spécifier les détails d'un tel programme scientifique. Mais je suis entièrement persuadé sur deux de ses aspects. Tout d'abord, les recherches doivent avoir lieu dans les universités, les centres académiques qui existent aujourd'hui. Mais, deuxièmement, ces travaux doivent être unifiés dans une certaine mesure par une infrastructure technique qui permettrait l'analyse et la comparaison des modèles des différents types, de leur principe de construction et de leur base algorithmique ainsi que de a base deurs données. Ceci permettrait un échange utile de nouvelles idées, des résultats de recherches scientifiques et de leur vérification. Toutes ces activités nous permettront d'approcher plus rapidement du jour où les méthodes basées sur les systèmes homme-machine fourniront une base scientifique solide pour les décisions internationales dans le domaine de l'environnement.

KALMAN: My views would be best explained in interaction with questions. Therefore, at this point I would like to be very, very brief. Let me begin with an irreverant phrase: my personal interests (as far as this conference is concerned) may be characterized by saying that I am student of the "modeling of modeling". Purely intuitive modeling activities of the type that Professor Forrester was alluding to are undoubtedly quite useful as a mental crutch for organizing large amounts of soft data. While a crutch is useful to those who cannot walk, if you *can* walk, then generally you can go a lot further. Some particulars. Organized science, such as physics or biology, make their essential contributions by letting us go beyond what might be called naive intuitive reasoning and raising our intuition onto a higher level where we can think in terms of new concepts. Thus the really important question from the scientific point of view (as far as modeling is concerned), is how to increase the *power* of the methodology of modeling. It is not enough to base modeling on currently available scientific facts (for example, using Newton's equations for modeling a mechanical system or using the current sociological data in modeling an urban system). If we wish to progress beyond naive modeling and want to develop a more scientific methodology, then we must have better insight into

the so-called "system" aspect of modeling. The really essential questions are those concerning the SYSTEM as a whole. Laws (as those of physics) are important also, but their knowledge does not immediately provide us with a deeper view of all their consequences. For example, in physics, even though the laws are supposed to "govern" and "explain" the behavior of molecules, we have not yet succeeded in deducing this behavior from the laws of quantum mechanics. (The remaining difficulties in this case are probably of a system-theoretic type.) So, in summary, let me say that I view modeling as part of an emerging reorganization of science, which clusters around the concept of an ideal (not necessarily physical) system. The various discussions we have heard here abundantly illustrate the fact that problems related to systems are beginning to assume a rather uncomfortably great importance. One of my well-known fuzzifying colleagues (who is alas not here), would have called attention to the fact that today is a Friday and, at the same time, the 13th. Under these circumstances it is necessary to be a little optimistic. Let me generate some optimism by saying that quite a bit of progress can be made, and certainly will be made, in the future to increase the power of modeling as a scientific method. And in the near future, modeling will cease to be merely the mental crutch that I referred to at the beginning, and it will be gradually replaced by sharper, more mathematically oriented conceptualization.

MOISEEV: Je pense que toutes les questions seront posées à la fin de la discussion—si nous avons le temps puisqu'il est dair que ce n'est pas aujourd'hui que nous allons finir mais plutôt cette semaine. Je donne la parole à Monsieur Churchman.

CHURCHMAN: I think I might begin by saying that as I interpreted the assignment given to our group it was to try to address the question of whether model building, and especially world model building, is a good idea as far as a plan of action for humanity is concerned. I would interpret that question in the following terms. I think we were asked whether model building serves a useful purpose. As I see it, model building is really an instrument that we can use or not use. In this regard I differ from J. Forrester. It does seem to me that he is right if what we are saying is that we should make our decisions on the basis of our thinking function. But a lot of our decisions are not based on thinking at all. They are based on feeling, or intuition, to use Karl Jung's distinctions between mental functime. Neither feeling nor intuition apparently work along the lines that model building does. I think we have a choice as to whether or not in a plan for action for humanity we want to base it essentially on the thinking function. If we do, then it seems to me very important to raise the question which has cropped up off and on in this conference, namely what the goal is that is supposed to be served by this instrument, which is the ethical issue. It was raised by Erick Jantsch in the very first session, where he was rather incredibly corrected because of his suggestion that we might go beyond efficiency and productivity. It seems to me to be pretty obvious that from any ethical point of view we *have* to go beyond efficiency and productivity. There are lots of things we do in this world that are ethically bad, but we do them efficiently and with a good deal of productivity. For example, the productivity of crime—which seems to be pretty efficiently done—is hardly justified in terms of ethical criteria. Yesterday, René Dubos suggested that we might go beyond energy growth as an ethical criterion, but then the gentleman from one of the developing countries rather neatly suggested that perhaps developed countries are not really developed. I think he said that they are overdeveloped. All of those I think are occasions where we raised ethical issues. I do not see how we can possibly consider the problem of world modeling without asking ourselves what it is humanity is trying to do or should be trying to do. Once that is settled, we can begin to ask whether this particular instrument for humanity's objectives called modeling is an appropriate one. I realize that a lot of discussion of this conference has been based on the assumption of crisis. If we were a military group, e.g. a Joint Chiefs of Staff trying to decide how to run a war, then we might not raise the ethical question; we would have assumed it had already been answered. But I do not think we are. We are scientists and for us the ethical issue must be the central one. Beyond that are questions whether these particular instruments like world model building are appropriate. I do not think the ethical issue is a vague question. We are here at the instigation of the Institut de la Vie. There is a great tradition of those who have concerned themselves with life in their contribution to ethical theory. Aristotle began it in the West and it has been continued down through the ages. A great deal of knowledge about what we ought to do compared to what we ought not to do can be gained from the knowledge of what we are like as living beings: again referring to René Dubos, this is what he was saying in effect: That many guidelines for human action and planning can be found in what we know about ourselves as a living species. I think we really have to go beyond biology in this regard because biology has often taken life in a narrower sense. But the Institute is called the Institute of Life and not of Biology, which I think is rather an astute naming strategy on their part because life consists not only of what occurs in biology but also what occurs in psychology, sociology, and in general in the notion of what we are like as a social and psychological living being as well as what we are like organically. So I think it is very appropriate that a question of ethics be raised in a conference of this kind, as a sensible one for further study, maybe for further conferences, so that we can come more clearly to grips with what it is that we as thinking types want to contribute to this thing called A Plan for Human Action. I do not see how we can have a plan for human action without developing some fairly concrete and specific ethical guidelines.

SHUBIK: I have several somewhat disjointed remarks. The first is that when one begins to take oneself too seriously a comparison with other alternatives is often a helpful way of getting back on the track.

In particular, as I was listening to the debate over the last few days over different sorts of models and different sorts of problems, I was reminded that Dean Swift once wrote a little pamphlet on *A Modest Proposal for the Solution to the Population Problem of Ireland.* His suggestion was the eating of babies, which you will observe both takes care of the meat supply and population control. I point out that this connects directly with some of the comments of Professor Churchman.

The group of us in our session were not in total agreement and I would like to touch on some of the differences. Concerning the observations of Professor Forrester, I personally believe that it is useful to think that all individuals operate on models. However, models of the mind and computer models are somewhat harder to connect than one might initially feel. I am reminded of my old friend, Professor McCollough, who when writing on this particular problem began his book with the quotation: "Tell me where is fancy bred / or in the heart or in the head?" I find that a DYNAMO model of a description of the role of fancy in human affairs would be verging on the ludicrous. I am perfectly delighted to be convinced otherwise, but it has been my painful observation that items such as really describing the appropriate metric or obtaining the appropriate dimensional description of variables that are used in common speech pose by no means a trivial problem. The reason why is the complexity of the human as a data processing and a coding–decoding device. The analogies we can make between him or her and the computer at this present moment are primitive. There is a fundamental problem in modeling concerning the use of different simulation languages. The simulation languages portray different conceptual views of the world. We are only beginning to know how to take these models of the mind and transfer them into policy models or computer models. I happen to be in complete agreement with Professor Forrester that it is terribly important that we try; it is important that we see what we can do. But it is one thing to invoke the desirability of doing something and it is another thing to have the ability to do it.

Now, turning for a moment to Professor Mesarovic, I note that programs are not processes and processes are not institutions. There is a large confusion in the concept of optimality and feasibility. Personally, I could in an aside argue that optimality is almost always not well-defined in most models we deal with. To talk about whether you should be striving for optimality or you should not be striving for optimality is to miss the point that you frequently do not even have a definition of optimality.

Economists love to talk about optimality. Yet frequently they fail to define the strategy spaces of individual behavior. If we look carefully at the definition of the domain of strategies for the individual, many optimal outcomes are not feasible. I am not merely suggesting this as an essay or lecture in economic theory. I am suggesting that although we can sit and generate plans from now until eternity, the unanswered question is: Can we translate the plans into implementation procedures? The other question is: Do the institutions exist which will be the carriers of process for these procedures. In general, my observation is that the answer is no.

Now, turning to something else, I do not wish—to use an American word—to be too curmudgeonly—(the translators might as well know that the translation into French of "curmudgeon" is "curmudgeon"). However, the point that I would like to make concerning what we heard from Professor Mesarovic is that I do not believe—at least personally—that I need a large scale computer model to tell me that world food problems are interconnected and that they go across national boundaries. I believe that most of the things that Professor Mesarovic was suggesting as important conclusions from his models were put into the models. Furthermore, not only were they put into the models, you did not even need the model to put them in. At this level good models of the mind are probably better and more flexible. Even though they are not as explicit, they may pick up more variables that are relevant than the models that are written out as computer programs.

I have made several pessimistic remarks. I wish to end with a few not-so-pessimistic remarks. First, in summary, I suggest that large scale world model building has so far been more hortatory and educational and a source of attracting attention than it has been a source of additions to the bank of applicable knowledge. There have been many conferences and many organizations, not merely the Institut de la Vie—the various academies of science, the Commission for the Year 2000, the Club of Rome, and other groups—have been interested in trying to bring some of these problems into the open for broad discussion. I think they have all helped in trying to call attention to a group of important problems.

On the more optimistic end of things, I note that although it has not been discussed in this meeting, the technological improvements in data processing and in computational ability have been absolutely enormous in the last 10 to 20 years. This includes improvements in computers, improvements in languages, improvements in time sharing, improvements in input–output devices, and improvements in data bank storage devices. You cannot ignore the cumulative effect of this enormous increase in information technology. Not only that. There has also been, I believe, a substantial improvement in theory concerning information handling and, for that matter, in basic economic theory, political science, in psychology, and in general in the behavioral sciences. They may not have got very far, but in comparison to where they were 30 years ago it is a completely different game. Having said that, it seems to me that regardless of whether we want to discuss our particular feelings about specific models at this moment, the preconditions for serious advances in large scale model building are already here.

Many of the technological preconditions have already been fulfilled. What do I personally believe remains? I believe that there is a two-pronged assault needed. One prong of the assault we have already discussed.

I use the word "propaganda" because I do not necessarily believe that it always has to be interpreted pejoratively. If you wish, we can call it public concern, or attention-getting, or call it softening up the funding sources. I do not care what we call it, but I think it is terribly important that the popularization and the attention-getting process go on. There is, however, a danger that if we try to present some particular model as a means for solving world problems, we will get attention, but we will alienate people once they perceive a failure to fulfil promises. We want to avoid this, but we want to continue the educational procedure.

The next step I believe involves institution building and the development of planning procedures. A plan is a piece of paper in the present. A planning procedure is a coding program to go into the future. An institution is the carrier of that particular process into the future. Our problem is: Do we have institutions that are viable and available for the carrying out of the programs we deem to be necessary? This, I think would require a lengthy discussion of the current institutions. I have some ideas myself, but I want to suggest to you that the problem is not world models, or world modeling. The problem is institutions to carry out types of change that may not have been necessary or may not have called for these machines of change 20, 30, or 40 years ago.

JENSEN: I always teach my students to work with reality and tell them that this nasty boy, i.e. reality, always spoils our good theories. The nasty boy was not in our room for the modeling sessions. None of the other groups had beforehand asked us questions. Therefore we were completely free with respect to choice of subjects. The specialists in the medical world are forced together around the sick man. They have to face reality here and now. We were not in that situation as we had no sick man to assemble around. In consequence, everybody delivered papers answering their own questions.

During the last two days we have learned that it was, maybe, the wrong questions, so our answers are, maybe, not really interesting for you. When next we meet I hope it will be as groups of interdisciplinary teams. Then we might be useful with respect to helping the economist to cut down his extension of uncertainty, to helping the energy people to make more realistic forecasts for decisions with a little more connection with institutional factors and their change over time, to giving the ecologist, by combining his findings with the decision structure, more force to present his findings in a more acceptable way to the bureaucrats and politicians.

And having been through that process we can discuss the possibility for construction of world models. Nobody has said that the big experiment outside our doors—the real world running in real time—is not able to find its solutions to the difficult problems of the future without the help of the participants in this conference. But it might be at the cost of a lot of dying people and a lot of losses of quality of life.

MATSUDA: One of the practical purposes of introducing scientific thinking in human life is to avoid experimenting with mankind himself or with the earth itself. Such "realistic" experimentation has often proven to be very costly to mankind and it is going to be increasingly more costly in the future. We simply cannot afford to continue in this way experimenting with ourselves and with our own planet. Experimental sciences enable us to "experience", so to speak, error or failure in a much quicker and less costly way. By sifting out such errors and failures, experimental sciences verify, establish and accumulate scientific laws which can safely, at least until refuted, be applied to a normative purpose in the real life. Global modeling is in its essence an experimentation, although with more of a logical rather than physical nature, and therefore the spirit of experimental sciences should once more be recalled. Namely, it is to "artificially" accumulate experiences. In this spirit, we should be exerting ourselves with more and more modeling efforts.

It goes without saying that global modeling requires global mind. However, actual decisions or actions can be taken only at the specific local units. Thus, unless a model is built in such a way as to identify the specific local decision- or action-unit, it will not lead to any concrete action which can contribute to mankind. Therefore, what I should like to see in the future global modeling is the identification of the practical decision- or action-units which could be incorporated into the institutionalized planning procedures at the level where the real-life decisions or actions could be carried out. Of course this might force us to get down to the national level and vastly complicate the modeling effort. But, if a decision or an action is not institutionally identified and consequently cannot be materialized, why a model?

A powerful way of linking global mind with local actions is provided by systems thinking. Systems thinking enables us to evaluate local actions in terms of their global consequences. Such local actions are mutually interacting. But this very interaction creates a characteristic mechanism, so to speak, which provides the medium for tracing out the propagation of effects of each local action, or each combination (portfolio) of local actions, through the system. Thus, the global implications of local action(s) can be identified. Conversely, effects of any global effort could be traced through this medium and evaluated in terms of their repercussions upon each local action-unit.

In view of this possibility provided by systems thinking, the second thing I should like to see in the future global modeling is the assessment of "portfolios of local decisions or actions in the global terms". So far, the discussions around the global models have tended to be piecemeal; namely one problem dimension is discussed at a time. Thus, energy is the problem at one time, and the mineral resources at another. Such piecemeal approach may give some clue to the solution, most likely to be of a type of patchwork one after another but can be dangerous in that the solution in one dimension, say energy, may create a serious, irreversible effect in another dimension, say ecology. In contrast, the portfolio approach could predict the

possible interactions among the decisional or actional dimensions and therefore enable us to envisage some preventive or compensatory actions in advance.

The third thing I should like to see in the future global modeling is more participation of the social, behavioral and political scientists. This is necessary in all the aspects of global modeling, in order to take full advantage of the achievements in the social, behavioral and political sciences, which I believe are rapidly being accumulated and made available to us. Furthermore, it is especially important in scrutinizing the regional or national value systems which must be taken into account in the future global models. In my mind there is nothing like a "global" satisfaction or dissatisfaction. The only satisfaction or dissatisfaction which is conceivable is at the regional or national level. We deadly need better understanding of the local value system in association with each local decision -or action-unit, whose role in global modeling in the future I have already emphasized upon. And here the social, behavioral and political scientists could make a vital contribution. The future global modeling would require a truly interdisciplinary team.

MOISEEV: Je voudrais observer, Messieurs, qu'il y a encore beaucoup de personnes qui sont insorites dans cette liste, et peut-être en a-t-il encore d'autres. Je vous demande donc de tâcher de minimiser la durée de vos remarques. Je sais que c'est une grande demande, parce que nous voulons avoir le temps de discuter. Je donne la parole à Monsieur Harmann.

HARMANN: I would like to make one point with regard to models. I hope it won't sound as a negative point; I think we can appreciate what models can do potentially in illuminating our thinking. The point I want to make is that they may also constrain our thinking. The history of science has many examples of models, or systems of thought, that turn out in retrospect to have had limitations. It is rather well known, for example, that the input–output models of the economists tend to de-emphasize some of the substitution possibilities. It seems to me that in this room we have heard two types of views expressed, if I can oversimplify. One is, that although the world has many problems, technology—combined with the natural working of the pricing system—has handled such problems in the past and is best left alone, because when we meddle with these mechanisms we tend to make things worse. The contrasting view is that the future is somehow very different from the past; that the problems that we face are essentially the consequence of our technological successes, the consequences of our cleverness and cheap energy; that they will not be resolved by the same approaches; that in the future we have a new kind of scarcity—scarcities of energy, of materials, of water, of land, of the waste-absorbing capability of the environment, of the resilience of life-support systems—and that this is, as we say in my country, a whole new ballgame. But the two perspectives are essentially very different. Uncertainty has been stressed here, and I think that we have to say honestly that we cannot at this point determine which of these two viewpoints is correct. In this situation of uncertainty, the way to play safe is to have alternative models, alternative ways of viewing things, alternative plans of action perhaps. I should just like to emphasize the dilemma that appears in this second view, because I think it is essential to our deliberations this afternoon as well as our concern with models this morning. Energy is very basic to many of the problem situations, as we heard. The United States is in a position where it cannot afford to go on expending energy at the rate at which it has. It cannot afford to meet the projected energy demand curve—partly because of environmental impact, partly because of the capital requirements to produce the energy, partly because of the inability to make payments for foreign oil. On the other hand, the United States cannot afford *not* to meet the projected energy demands, and the reason is very simple. GNP growth is directly tied to energy growth, and the input–output model emphasizes this. GNP growth is directly tied to employment, and we deeply fear the unemployment that would come if we did not spend this energy. To expand this, to make this dilemma a little more broad, think of two clusters of problems that face the advanced world. One cluster would be aided if somehow we could cut back on energy use. This is the cluster that has to do with the problems of energy supply, the way energy use impacts on the environment, the various kinds of material shortages, pollution problems, and related problems. The second cluster, quite in contrast, would be aided if we could somehow expend more energy and use more fossil fuels to produce more fertilizer and more pesticides. These are the problems that relate to unemployment, to the gap between the rich and poor countries and the world food problem. Just in passing, we have heard that if we had unlimited nuclear power, that would solve some of our dilemmas. But can you see the contrasting nature of these two problem clusters? It becomes clear that if we had nuclear power available tomorrow, cheap and in unlimited supply, we would still essentially have the same two clusters of problems with slightly different emphasis. Population is involved here, but population itself is a result of a technological intervention in the world. So that the dilemma is an extremely basic one; it has to do with the incentive structure of the whole industrial system which we have set up. It is essentially a systemic dilemma. The various specific problems that we have heard mentioned here are manifestations of that systemic dilemma. Bear in mind I am only trying to describe one or two views and I am not claiming that it is a view everyone must hold. But if it is plausible at all, then we have to be sure that somehow we keep open the alternative perceptions to include it as a possibility. This second view would view the whole industrial era as a jump from the low technology kind of society to some sort of high technology equilibrium society. Some kind of frugal society would appear to be a necessity, a society that does not center around productivity and efficiency as its highest goals. Yet to achieve such a society would require a systemic change of magnitudes that we do not know how to achieve smoothly. I have taken your time to elaborate

on this a little bit because I think it is terribly important for us to realize that we are not talking about some academic quibble about whether one model or another is more suitable. Rather, we are talking about differences in perceptions which are so vast that the whole way we go about devising a plan of action for mankind is going to be affected by the way in which we perceive the fundamental nature of our problem. In our discussions this afternoon, then, I would hope that we might somehow incorporate alternative interpretations of the present world situation and deal with the crucial question of how, if indeed we need to achieve a frugal society, we can go about that systemic change without a collapse of the present system as we know it.

MOISEEV: Je donne la parole à Monsieur Benard.

BENARD: L'enthousiasme pour la modélisation et les grands systèmes réconforte et en même temps inquiète un peu l'économiste que je suis. Non pas que l'économiste ignore ou rejette la modélisation. Bien au contraire, comme on l'a rappelé, l'économie a été la première dans les sciences humaines à élaborer des modèles, les uns purement théoriques, les autres numériques, et aussi, a été la première à appliquer certains d'entre eux. On a parlé du 18ème siécle. Je rappelerai le Tableau économique de Quesnay et des Physiocrates. Mais, plus près de nous, au 20ème siècle, la société d'Econométrie a été créée à la fin des années 20. Le Professeur Tinbergen, l'un des nôtres, et des plus éminents, a été l'un des premiers à élaborer des modèles économétriques. Le nom de Leontieff est bien connu, et j'en passe. Cependant, plutôt que faire de l'histoire, je voudrais essayer d'écarter quelques-uns des malentendus qui peuvent se glisser entre nous, et ceci en vue de développer une collaboration entre les différents spécialistes et, parmi eux, bien sûr, les économistes, pour construire ces modèles plus généraux, ces systèmes dont nous sentons tous la nécessité. Or, entre les modèles économiques tels qu'ils existent, tels qu'ils se sont développés, notamment au cours des dernières décennies, et les embryons ou les projets, ou déjà les réalisations de grands systèmes, interdisciplinaires, il y a, certes, des différences mais aussi des convergences et même des identités de structure.

Tout d'abord, un modèle économique peut avoir les mêmes caractéristiques structurelles que n'importe quel autre. Il se caractérise par un ensemble de relations cohérentes de variable les unes exogènes, les autres endogènes et de paramètres. Il peut être statique ou dynamique, certain ou aléatoire, admettre ou non une optimisation, etc.

Il est donc complètement erronné d'assimiler comme certains ont tendance à le faire: modèle économique à modèle statique et modèle sociétal à modèle dynamique, ou encore de rejeter l'optimisation hors de l'analyse de système, l'optimisation n'étant en définitive que la recherche d'un extremum sous contraintes.

En second lieu, si comme je le comprends, l'analyse de systèmes revient à interconnecter de façon cohérente des modèles (ou sous-modèles) spécialisés chacun dans un domaine (technologique, économique, sociopolitique) ou dans un type de problème (pollution, distribution des revenus, exploitation des ressources naturelles) tous les scientifiques, et les économistes les premiers, ne peuvent qu'y être favorables. Car la construction d'un "système" revient alors à rendre endogènes pour le système certaines des variables ou paramètres qui sont exogènes pour les sous-modèles constituant le système, et, par suite, à introduire des rétroactions ("feedbacks") entre ces sous-modèles. J'ai pour ma part, essayé d'en donner un exemple, bien que limité, dans mon propre rapport au congrès, intitulé "The proper measurement of economic welfare". Ainsi se trouve généralisée la notion même de modèle.

Toutefois pour que nous puissions sortir des constructions purement conceptuelles et passer au stade opératoire, une condition essentielle doit être remplie. C'est que nous disposions des observations numériques, en général statistiques, permettant de vérifier empiriquement les formalisations théoriques avancées, ou, plus exactement, d'écarter celles qui sont réfutées par l'observation. Règle qui en implique immédiatement deux autres: premièrement n'introduire dans la structure systémique que des relations ou logiquement évidentes ou empiriquement réfutables; secondement rassembler le matériel statistique indispensable à ce travail de vérification-réfutation.

C'est pourquoi j'estime, contrairement à ce que j'ai cru entendre soutenir ici, que l'analyse systémique ne dispense pas du tout, bien au contraire, du recours à l'économétrie, à la sociométrie, bref à toutes les disciplines qui s'efforcent de vérifier des relations sociales à partir d'observations statistiques. Dans les sciences humaines, où le plus souvent l'expérimentation de laboratoire est impossible, ce type de vérification, dont les méthodes ne doivent pas être figées, est notre seul recours.

La grande difficulté vient de ce que dans les domaines sociaux, autres qu'économique, sociologique, politologique par exemple, le matériel statistique est beaucoup moins abondant et fiable; de sorte que l'un des soucis primordiaux des partisans de l'analyse de système devrait êrte, me semble-t-il, de réclamer des enquêtes statistiques en ces domaines.

Je ne vois donc pas au tout d'opposition mais, au contraire une très forte complémentarité entre analyse de systèmes et économétrie (ou sociométrie etc . . .) à condition, bien sûr, que les échanges nécessaires se développent entre ces disciplines.

Voilà, Monsieur le Président, mes chers collègues, ce que je voulais dire dans un souci, encore une fois, d'écarter des malentendus et de faciliter la collaboration que je souhaite et crois fructueuse entre nous tous. Merci Monsieur le Président.

PIORE: I should like to make a very pedestrian observation, nothing very profound. As one moves in creating an international institute that would pull together all these model builders or world global model

builders, it becomes very important that the academic community document its work. I do not know how to stress it. One of the difficulties in this area, one of the difficulties in engaging in debate, is that one lacks documentation. Let me try to give you an example of the computer industry. Much of the money spent on programming is spent on documentation, quite apart from writing the program. In the academic tradition, one does not document it. I guess it starts with the physicists. The physicist does not document how his laboratory is wired; he knows it. He wired it himself. He knows where everything is, where things will go wrong. In this area, these wires are the things that really make it operate. Also, in a sense, they tell you what your assumptions are, etc. That means that someone has got to take the time and write this down. I am talking from experience. This is true of research laboratories in industry as well as research labs in academia. So as we move into an international institute, whether in France or England (depending on the governmental decisions), let us get our house in order.

DALKEY: In the short time that we had to discuss some of the potentialities for models, looking at courses of action for mankind, it was impossible to cover all the areas of modeling technology that exist. I should like just to comment on one which we did not have a chance to discuss, but interestingly enough was brought up by inference by some of the comments made by the speakers at the table. First, I should like to emphasize a comment that was made by Professor Forrester. The fact that we cannot get away from using models is both true and extremely important. But also the comment made by Professors Churchman and Shubik that the models we have in our mind are very different from the kinds of models that are normally represented in a computer, is also true and has to be taken into account. There is one other aspect about these models we have in our minds that is equally important and that is that they are all very different for different people. There is an enormous diversity in the ways of looking at the world that we all carry around with us. That poses a very serious problem as to what to do if you are going to use the wisdom of various people in order to model the world. There are roughly two ways to approach that. One is to have one creative person formulate his model—perhaps with the help of other people—and he can even use these other people to furnish intuitive inputs to his model. I assume that one could refer to Professor Forrester as one of those creative people. That is one of the ways that you can arrive at the utilization of some of the perceptions of different people. There is a quite different route that you can take. That is, you can form something that might be called a collective model. The techniques for getting collective judgment on individual questions are beginning to be fairly well formulated. Elementary techniques of that sort have been given the nickname "Delphi". Techniques for formulating collective models are a good deal more primitive. However there are such techniques being examined. Among them, for example, are some of the dimension reduction techniques such as factor analysis, cluster analysis, or multidimensional scaling. These are ways of taking long lists of suggested factors on the part of different members of a group and collapsing those very long lists into shorter, more manageable, more coherent lists. In that way you can take the perceptions of many different people and get all of those perceptions into a single model. As I say, all of this is very elementary at the moment, but suggests the possibility that the development of technology for creating collective models is a researchable subject and is one that is under progress.

MOISEEV: Je donne la parole à Mr. Cloud.

CLOUD: I should like to address my remarks to the limitations of global system modeling which is one of the subjects under discussion this morning, and to reinforce some of the things that were said so eloquently by Mr. Jantsch and others in this audience. My remarks are more general and perhaps express the sentiments of others at this—at least I hope so. I will try to articulate them because I am afraid they may fall between the cracks of the special discussions of the various groups. I would like to propose two statements of view here that I hope might find support among the group as a whole.

I—We recognize that earth's resources, although large, are finite and that certain constrains are unavoidable. Larger populations than ever before are consuming larger quantities than ever before at faster rates than ever before. To traditional fiscal costs of production must be added environmental and social costs. We must be aware of the permanent conversion from free to bound energy according to the second law of thermodynamics. We have recently emerged from a period of declining costs, while the high-grade ores of virgin continents were being consumed, soils degraded, and environmental and social costs externalized. Now the world faces a prospect of rising costs in all terms and the placing of great strains on its ability to feed people adequately and provide resources for high technology societies. Added to this is a pressing need to move vigorously toward equity among peoples, nations, and generations. To concentrate only on the most central issues, two main barriers thwart the attainment of equity and the achievement of a sustainable balance between man and his resources. First is the high *per capita* consumption and waste of affluent peoples and their general adherence to the concept that continued growth is a basic good in itself rather than one possible way of enhancing the human condition—good in some situations, but not for all. It is good, for instance, for a child to grow to adulthood, but excessive growth creates a monstrosity. Second, rates of reproduction beyond bare replacement, leading to increases in population that in the high birth-rate countries nullify gains in production and technology that otherwise might improve the level of living. This applies to food and the provision of suitable shelter as well as to literacy, public health, and the generation of the finished materials that can make life easier. We therefore strongly recommend that it should be urged on all nations and peoples that:

(1) excessive consumption, inefficient use of materials, and waste should be reduced by whatever means are available and consistent with human dignity;
(2) all populations now reproducing themselves at greater than bare replacement rates should seek to reduce their rates of population growth, aiming toward the attainment of bare replacement levels as soon as possible, again, using all means available and consistent with human dignity.

II—Although we have not attempted here to go into the very central question of establishing and perpetuating world peace, we feel impelled to identify another great problem for the future of mankind. That is the development of the nuclear breeder reactor. Its results in the generation in large quantities of a substance that is lethal in microgram quantities, and from small quantities of which homemade nuclear bombs can be made. We refer to plutonium 239. If man is so thirsty for energy as to seriously enter into such a Faustian bargain as the global production of breeder reactors, he is indeed in desperate straits. Although we recognize very serious problems of energy supply ahead, not only in the long range future but also in the next several decades, we do not believe the problem calls for such desperate measures. We further recommend, therefore that:

(1) the nations of the world discontinue further efforts to develop the breeder reactor or any other devices that use and generate any product approaching plutonium 239 in its potentialities for destruction;
(2) that instead, efforts be made to improve long range energy sources.

OYAWOYE: I will be very brief, Mr. Chairman, I think the natural theme of the conference is such that I think that life and humanity ought to have been more emphasized. With that, I think it is not only important at this conference that the ethical question should be raised and discussed but that it should in fact be emphasized. I should hope that at a future meeting of this type this will in fact take place and that there will be much better representation for people not only from developed and overdeveloped countries, but also from underdeveloped countries. I think there is a need to define at some point what constitutes excess in well being. I say this realizing that it is a very abstract thing and extremely difficult but I would hope that nationally, that is within a country, one ought to be able to describe at some stage what constitutes such excess, the input of energy and resources into which therefore constitute waste. I suppose this could also be done internationally between countries as within a nation between people.

DATTA: We are at the end of our conference in which we have brought out a number of useful recommendations leading towards production of more energy, creation of more wealth, its growth and control, more equitable distribution of resources, and more advancement to meet the material needs of people and material progress. Emphasis has also been given to the plan for a better quality of life rather than for an ever-increasing quantitative growth, and rightly so. The time is quite appropriate for this intellectual gathering to pause and think—where these material achievements will lead humanity to? We should be able to forecast properly and give humanity definite directions for the future. To what extent should we go ahead with material progress? And if we have to stop—where do we stop? If we aim at attaining "quality of life" wherein peace and happiness will prevail, is it, then, the mere achievement of material needs which can give us these? Certainly minimum basic needs in respect of food, housing, clothing, medical aid, and education are to be met. "Quality of life" cannot be attained by merely satisfying these basic needs. What else, then, is required? If you look to the history of world since the days history is known, even the wealthiest, materially successful person died unhappy and without peace of mind. In the mind can be sown the seed of war, and again, it is in the mind alone the seed of peace can be sown. It is my conviction the mind has to be elevated to a certain higher state wherein peace and happiness are the objectives. We accept, then, the basic material need of life as means to an end. In Vedic concept and in its practice in India, it is possible to elevate the mind to higher and higher planes wherein it is no longer the mind which is active—it is something beyond mind; at that elevated state it is possible to visualize the glimpses of real peace and happiness. Thus man can surpass the limitations of his body and go beyond his mind through his mind. At this elevated and exhalted state, he is in his divinity. Divinity resides in man; divinity is to be awakened in him by himself; the outcome is divine love. Divine incarnate is with us. If the quality of life is the aim, and peace and happiness of man are the objectives, the training of mind, the elevation of mind to a higher superconscious state, the awakening divinity in man by himself must find place in the plan of actions for mankind.

FRIEDMANN: I am a Chilean who has been working in Mexico since September 1972. For 10 years I worked in Chile in design and in the field as a civil engineer. Subsequently I studied operations research and economics in Berkeley and for another decade I have been trying to use this background on problems related with development. I mention all this so you may better interpret some of my biases as reflected in my comments.

I should like to offer two recommendations for future work by L'Institut de la Vie on the subject matter of the conference. First, on the nature of questions to be addressed, I should like to suggest that special emphasis be given to matters of equity. That is to say, that the analytical efforts focus on how on-going

processes and alternative actions under consideration might affect the less-developed countries and the deprived and marginal people within nations, such as workers in agriculture and extractive industries, women (who are so conspicuously absent from this conference), and those who are not yet born.

My second recommendation has to do with the process of implementation. I feel that efforts should be made to develop institutions which channel general public support and promote and facilitate broad participation by the mass of the population in the definition of objectives and identification of alternatives.

Behind these recommendations there is a concept of development, of progress for humanity, in relation to which I would like to recall what M. Marois told us in his very enlightening and moving speech during the opening session of this conference:

> Mais la science n'est qu'un moyen. Inévitablement se pose le problème des fins et la nécessité de leur formulation claire: développement de tout l'homme et de tous les hommes, style d'existence et qualité de la vie, modes de société, classement des priorités, tension dynamique entre compétition et communion, efficacité et poésie, biens matériels et béatitudes . . .
>
> Est-il possible de substituer aux régulations paroxystiques par les crises, des régulations pacifiques, conscientes, grâce à une appréhension des données objectives du problème, en mobilisant les moyens de la science et le sentiment d'interdépendance, de solidarité, de communauté de destin?

I am convinced that only by mobilizing the sentiments of interdependence, solidarity, and community of destiny, will we make real progress towards the building of humanity. These sentiments depend very much on the experience of progress.

The main obstacle within the underdeveloped world stems from the view of limited good that prevails in those societies. Most people do not have experience with or at least have not become aware of the possibility of progress and in particular are not fully aware of the importance of cooperation. They have seen too often that another person's gain is their loss. They perceive all situations a zero-sum two-person games. With that experience it is not possible to implement actions that require cooperation and enhance sentiments of solidarity or a community of destiny. Something must be done to show that many opportunities exist for cooperation by which all participants will gain. The misery of large fractions of the population in the underdeveloped world make it imperative that as a first priority the worst forms of poverty be eliminated as a precondition for moving towards a world based on a feeling of community of destiny. Therefore, the problems to be addressed when designing a plan of action for humanity should stem from the realization that not enough food, sanitary facilities, etc., are available to ensure the development of children to their full potentials in Asia, Africa, or Latin America, and not from a concern with availability of beef in the United States or with scarcity of cheap fuel for the cars that pollute the large metropolii in the developed world. This requires an important shift in the focus of discussion on world problems.

A further element in the concept of development I would like to stress is that for progress to take place one must enhance the ability of man and mankind to identify their own problems and to act effectively to solve them. This thought is behind my recommendation relating to the process of implementation of whatever activities are pursued in order to achieve the objectives of this conference. Continuing efforts to explore the questions that have been raised and to implement the recommendations that are being made should be based on the broadest possible public support. This support must come not only, or mainly, from those who have political power but progressively more from groups that represent the full range of sectors in the world. The constituency for the kind of activities that prompted the Institut de la Vie to organize this conference should not only be the national governments but all organizations that represent the general public like the United Nations specialized agencies, world and regional development banks, groups of the business world, parliamentary associations, international associations of political parties, groups representing concerned citizens, labor unions and professional associations, churches, etc.

Although I believe that what I say is valid for all the activities relating to efforts for analyzing and finding solutions to the problems which obstruct the building of one world, I would like to illustrate my point with a particular reference to the design of global system models. In the session on design of global system models and their limitations, we had an excellent illustration of the fact that models are built for the purposes of the one who pays for them. Dr. Brewer reported his and Dr. Shubik's analysis of different experiences with large system models. They told us that frequently models are not built to obtain an answer to a problem but to help the person or institution who paid for them in selling a solution which he has already chosen.

I should not like to see something like that going on when dealing with global problems. If we are honest about our interest in building models that are capable of analyzing the problems of humanity, we should make every effort to broaden the sources of support for model building activities and communicate to the general public the result of the analysis.

It is tempting—personally rewarding and expedient—to become the modern priests who pass the divine revealed wisdom from the computer tabernacle to the powerful in the land, but we should be fully aware that the way we respond to that temptation determines in an important measure if we shall live in a humanistic, open, democratic society or in a highly centralized beaurocratic system in which at worst Big Brother,

either left or right, will be always watching and giving us its double talk, and at best we shall be taken care of by enlightened despots.

JANTSCH: I should like to make a brief statement on a point which is of great concern to me. That is the impact of models or any kind of forecast on people before any question of the usability of structuring action comes into play. I can see that models or forecasts in general arouse or enhance feelings and attitudes in us which can be placed in a wide spectrum, the extremes of which are fear and hope. It is really fear and hope which motivate us in dealing with our future. I do not think that we should resolve this to either one side—to blind hope or to blind fear—but really recognize it as a creative tension which brings out our own creative responses. Hope goes very much, as I see it, with the recognition of mankind being a system which is alive, and that means a system which evolves. Evolution does not mean growth in quantitative terms and it does not mean a smooth transition. It means mutations. Evolution is a large scale quantum process and in the human domain it has always worked in such a way that cultures followed each other and that social systems moved to new dynamic regimes. Hope is in the recognition that there are new levels of dynamic regimes that mankind can mutate to. Fear, on the other hand, is linked to the lack of this belief and to the response which tries to stabilize what we have in hand. Almost all of the present formal planning is geared to stabilization. I would also say that the bulk of the efforts in world modeling is geared to a behavioristic outlook. A behavioristic outlook means the study of structures, the study of systems pressures in the presence of an entity, namely mankind, which behaves in certain predictable ways. I would call behavioristic models in themselves a very valuable device to study systems pressures, and in particular to study the interaction of systems pressures and to demonstrate that we have to deal with many factors simultaneously. But a behavioristic model is also a model of a Skinner box. A Skinner box is a rigid structure which is constructed in such a way that only certain processes in the behavioral spectrum of an animal come into play. So it elicits a certain behavior, a conditioned response. If we take behavioristic models seriously as a plan for action and base our policy decisions on it, we would have to construct a Skinner box for the world. This means that we have to have an élite—some Mr. Super-Skinner outside of our society—who constructs this box and makes sure we behave as expected from us.

It is like a big jail. In the human domain a jail is a Skinner box. I should not like to live in a jail. I think we have to supplement these kinds of models with other models or with other kinds of thinking which bring into play more the lives in human systems. Life means also the possibility to mutate, to come to new value sets, to new kinds of ethics, to new kinds of paradigms in all our ways of thinking. Maybe experimentation plays a big role in furthering evolutionary processes. I think that planning has to become much more the furthering of the next mutation and not just the stabilization of what we have in hand. I do not say that stabilization is bad because it permits to act out energy. But once this energy has run down, we need a mutation to renew the dynamic level. I think that experimentation could help in that. I have been wondering for some time if Mao tse-Tung's Cultural Revolution in China was not a very large scale experimentation. I do not know the purpose of it; I do not know whether it was considered a success by the initiators, but it seems to have been fairly well managed. Also it created quite a stir. Maybe this type of openness to the life processes which run through the human world is important to let processes define the structures which are to come and which again will permit us to act out energy in a focused way. But first, I think, we must have the belief that there is a new dynamic regime to which we can go and that the world as we know it, structured as it is, is not the only possibility. We cannot or even should not try to structure it in any dictatorial way. Anyway, I believe that if we try to freeze in an excessive way the present situation, the life forces in mankind will break through eventually—with a delay of 10, 20, or 30 years maybe—but then in a much more destructive way.

LINDBECK: May I just give a comment to Mr. Shubik's statement, which I basically agree with. If I understood him correctly, he said that more important than to build "world models" is to create institutions which can handle the problems we are confronted with. I entirely agree that often we do not have institutions for solving *new* problems, but mainly institutions for solving previous problems. That is in the nature of things. However, I would like to emphasize another thing. More important than building "world models" is also to study the *partial structural relations* which are assumed to be known in these world models. A basic flaw in all these world models is, of course, that nobody has the information needed about the partial relations which make up the world model. And as we know, the quality of a model cannot be higher than the quality of the assumptions which are put into it.

Perhaps we can talk about two different types of information here. One refers to the fact that those who have built the models have not used the best information that is available in various branches of the natural and social sciences. For instance, economists have pointed out that the constructors of "world models" have not used information from economics about adjustment processes, for instance related to changes in relative prices, which would also influence the continuous change in technology, etc. And the models do not include political adjustment processes either.

A second point is that much of the information which should be needed for such models is not known to *anybody*. I think that the conclusion has to be that the emphasis in coming decades has to be *not* on the task of building such large models, but rather on the task of filling the "knowledge" gaps relating to the unknown partial relations.

Let me just end by saying that, as Benard pointed out, economists have for some 40 years tried to build quantitative econometric models of the economic system. This is, of course, a much smaller and much easier system than the systems people try to grasp by the "world models". It is difficult to summarize the success of these attempts to build econometric models. But I am afraid we have to say that the models are still not very satisfactory—either as forecasting devices or for analyzing the effects of policies. The best forecasts in many countries are today *not* made by those large scale econometric models at all but by completely different techniques such as questionnaires to businessmen and consumers about their plans. I would think that the main achievement of the econometric models is rather that they have had a feedback on economic theory. Economic theory has been changed when previous assumptions have proved wrong.

If this is the experience of econometric models, which are much simpler than "world models"—comprising social processes, environment, biology, etc.—it should be clear that the publication of "world models" has been *a premature application of rudimentary knowledge* or rather perhaps of *nonexisting knowledge.*

MOISEEV: Merci M. Lindbeck. Il y a encore trois personnes qui ont demandé la parole: M. Marney, M. Duloy et M. Rubin.

MARNEY: As a member of the working session on systems modeling, I want first of all to express unreserved admiration for the presentation we have had from the panel. If they are taken as perfectly representative of our group, they will gain for us far more credit than we deserve.

With perceptions somewhat sharpened by a much-needed cup of coffee, however, I begin to be more than a little perturbed by what I believe to be a certain *over* effectiveness in impact. By their forceful, individualist assertions they tend to present our work in rather sharply divergent modes of emphasis within systems modeling. While we, as a special interest group, prize these panelists precisely *for* their strengths in diversity, the general audience will hardly be able to resist the impression that such distinctive modes could not conceivably be connected in any coherent manner. Our considerations today lie toward potentialities as well as limitations; therefore, I wish to do what one can in a few moments to indicate at least some promising lines of connection.

Let us begin with Professor Kalman. His appeal is that we construe systems modeling in the deepest sense as an extension of a venerable effort to increase the range of our rationality. He insists that we give first priority to an emphasis on modeling as a scientific activity marked by penetrating conceptions and theoretical rigor. No one could fail to respond to that appeal. But note that he tends to be disregardful of his best allies. In applying a perjorative term like "crutch" to techniques so far attempted in immediately practical world systems modeling he is surely too sharp. Modeling of the range of the Forrester-based effort of Meadows *et al.*, of the Mesarovic–Pestel approach—and, worldwide, the variants of Kaya in Japan, Roberts in the United Kingdom, Linnemann in Holland, and Herrera in Argentina—all of these attempts contribute as necessary first steps. Historically, most significant improvements in rational method have been the combined accomplishment of those willing to begin by grappling with reality in immediate experiential analysis; of others moving then into the stage of conceptual analysis delineating in ordinary language those primitive notions, assumptions, procedures which would be fruitful; and of still others bringing ruder beginnings to a more satisfying culmination at the deep theoretical level which Kalman points toward. I say that without this iterative, cyclical interplay between experiential attempts, conceptual analysis, and theoretical development, we cannot readily gain those ends that Kalman most desires.

Turning now to Professor Churchman, we are recalled to consideration of an option which he believes has been much undervalued, an option whose importance none would deny: that greater dependence might well be placed on the *un*-understandable subtlety and elegance of intuitive thought as an alternative to an overly technocratic form of modeling. Essentially, his emphasis in on the proper role of *feeling* in human judgment. But the central thrust of the systems approach in inquiry is precisely the holistic ambition to break through traditional barriers which have been driven between science and the humanities—between feeling and acting, knowing and valuing. That this is the ambition of a system approach Churchman himself, I am sure, has written a number of books to show. Thus I simply want to suggest that Churchman's remarks entail, not a fundamental revision, but rather the necessity of holding always an ideal conception foremost in our minds: that systems modeling at the practical level must ultimately prove to be sensitive to the intuitive-regulatory capabilities of human judgment in selection of purpose and satisfactory behavior.

Notice that this connects directly to Professor Shubik's point of emphasis: the near-incredible complexity of any attempt to map the subtle capabilities of *cognitive* modeling and human intelligence onto algorithmic procedures and computer-assisted logical processing. This is certainly unchallengeable. Yet, to the extent that this can be done, to whatever extent one can succeed in formalizing any effectual level of cognitive process via "programming", to that extent we open new degrees of human freedom—freedom to move to identification and attack on higher order problems which sheer limited cognitive-cybernetic *capacity* has shielded from adequate attention.

Now there is a consideration at this point which may be even more significant. We may not need, ever, to choose to try seriously to approximate cognitive processes at the functional level of system modeling. Why? Because we have recourse to a technological capability which admits of interactive man–machine procedures in analysis—procedures of precisely that type which Academician Moiseev, I believe, is currently engaged in developing strongly within his institution. The presentation by Professor Paul Medow during

be known about the system modeled; (2) our computers are too small to handle many relevant details of these very, very complex and large systems. Some of us working with models which represent much smaller physical systems are worried when we look at these all-inclusive or global models because of their seemingly unrestricted use of lumping (aggregation) and oversimplifications, both of which are forced upon the modelers by computer-size and speed limitations. My question deals with an alternative modeling procedure. I wonder whether such an alternative was sufficiently studied. The alternative strategy, instead of utilizing a single model of the whole, large system, would be based on a series of models of smaller subsystems. These smaller models would interact on the computer with each other in a much weaker way than it is possible when one treats the whole large system at once. However, note that interaction between subsystems still would take place, though perhaps not continuously. Such procedure, if properly developed, first, would certainly make it possible to put much more detail into the model. Second, it would make it possible to utilize much more fully the knowledge (and even models) which have accumulated in various other fields, e.g., economics, earth sciences, biology, etc. At present, I think that the input of these various relevant sciences often is not fully utilized by the global modelers. My question is: Are these "weak interaction" techniques adequately developed? If they are not—can they be further advanced? If such techniques do exist, it seems that information about them should be given to those of us who develop models of single processes or of smaller systems so that we could help the integrators more efficiently in integrating our more restricted models into their large system models.

Chapter VIII

CLOSING SESSION

Président: J. Coulomb

CONTENTS

PRINCIPALES CONCLUSIONS DE LA CONFÉRENCE MONDIALE DE LA POPULATION

L. Tabah

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La Conférence Mondiale de la Population organisée par les Nations Unies, et la première à aborder le problème sur le plan politique, s'est terminée il y a moins de quinze jours à Bucarest. Des délégués du monde entier s'y sont réunis et ont notamment adopté un Plan d'Action Mondial de la Population, dont la préparation était fondée du point de vue scientifique sur les bilans de nos connaissances dressés par quatre colloques tenus l'année dernière, sur la population et le développement, la population et la famille, la population, les ressources naturelles et l'environnement et la population et les droits de l'homme. Le Plan a été adopté par consensus auquel se sont joints des pays aux conditions idéologiques et matérielles aussi différentes que les Etats-Unis, la Chine, Cuba, l'U.R.S.S., le Brésil, la France, l'Algérie, etc. Je voudrais brièvement vous rendre compte de ce document essentiel, qui n'a d'ailleurs pas été adopté sans de très vives et très passionnantes discussions.

Le Plan comprend quatre parties:

1. Historique.
2. Principes et objectifs.
3. Recommendations sur les mesures à prendre.
4. Recommandations sur l'application du Plan.

1. HISTORIQUE

C'est, en fait, une introduction destinée à indiquer le "pourquoi" du Plan. Il y est d'abord rappelé que le Plan se caractérise par une certaine spécificité, étant limité aux variables démographiques. Le Plan n'est donc qu'un fragment, un rouage d'une action internationale concertée, plus vaste sur le développement, s'ajoutant à bien d'autres stratégies, par exemple sur l'agriculture, l'alimentation, l'emploi, l'éducation, l'environnement, l'application de la science et de la technologie, dans le cadre de ce que l'on appelle la Deuxième Décennie des Nations Unies pour le Développement et le nouvel Ordre Economique International qui commence à prendre forme. Donc, premier point d'importance majeure, il s'agit d'une pièce limitée à la population et n'ayant nullement la prétention de traiter de l'ensemble des problèmes qui préoccupent le monde, tout en tenant compte cependant des stratégies et programmes déjà en place.

Certaines données de la situation démographique mondiale sont ensuite rappelées. Le fait que jamais les hommes n'ont eu le spectacle d'une telle croissance dont l'élan n'a fait

que s'amplifier depuis la deuxième guerre mondiale. C'est un phénomène insidieux dont la lenteur l'a longtemps soustrait à l'attention de la communauté internationale, par ailleurs peu disposée à le discuter, et qui a déjà développé bien des conséquences que l'on s'efforce aujourd'hui de corriger. Nous parvenons cependant de toute évidence à une époque où les taux d'accroissement atteignent des sommets. Mais le mouvement de reflux sera plus lent que la montée de la population et le rétablissement des équilibres perdus va exiger au moins six à sept décennies en raison du potentiel d'accroissement qui s'est accumulé dans les structures par âge. Ce n'est pas l'un des moindres paradoxes que de constater que le problème démographique contemporain, dont les origines remontent à une trentaine d'années, avec le début de la baisse de la mortalité dans le Tiers Monde, ne pourra être dénoué que par un renversement de tendances échelonné sur près de trois quart de siècle.

Ce caractère d'inertie est tout à fait fondamental pour comprendre la situation aussi bien des pays en voie de développement que des pays industrialisés et permettre de risquer des hypothèses sur leur avenir. Quelques chiffres sont sur ce point révélateurs: imaginons que les couples adoptent dès maintenant dans les pays industrialisés une dimension des familles permettant un simple remplacement des générations, ce qui est déjà le cas pour nombre d'entre eux, et même au-delà. Nous calculons que ces pays s'accroîtraient encore de 27% avant d'atteindre la stationnarité qui ne sera totale que dans 70 à 80 ans. Si, autre exemple pris cette fois dans le Tiers Monde, les couples d'Afrique de Nord changent progressivement leur comportement, mais de façon plus marquée, venant de plus haut, de sorte que le taux de remplacement tombe à l'unité en l'an 2000, la population de cette région serait appelée à tripler avant de connaître l'état stationnaire dans environ un siècle. Ces calculs montrent combien les structures actuelles pèsent sur un avenir qu'elles conditionnent. Il est nécessaire dans un accroissement du moment de séparer ce qui revient aux conditions actuelles de ce qui revient aux structures, c'est-à-dire au passé. On peut dire que dans de nombreux pays en voie de développement la moitié de l'accroissement est dû à la vitesse acquise et l'autre moitié aux comportements actuels. En d'autres termes, la moitié de la croissance est en quelque sorte une servitude et l'autre moitié accessible à la volonté de changement, qui connaît elle-même ses propres facteurs d'inertie. Aussi tenant compte de ces deux sortes de résistance, démographique et sociologique, la marge d'incertitude est-elle faible d'ici la fin du siècle. La population du monde s'éloignera peu de 6,5 milliards et nous devons dès maintenant vivre avec cette idée et nous préparer à y faire face.

Bien d'autres considérations figurent dans cet avant-propos, mais je voudrais attirer votre attention sur la dernière phrase, qui met l'accent sur la nécessité d'une action suffisamment anticipée et qui dérive directement de la valeur exceptionnelle du temps long en démographie à laquelle je viens de me réferrer. Une ligne de conduite fondamentale devrait être de se laisser guider par la pensée anticipatrice, ne plus partir tant du passé, qui est d'ailleurs surtout connu et analysé pour les pays industrialisés, que de l'avenir. La lecture de l'avenir doit plus nous requérir que le simple commentaire du passé. Aussi, même lorsque la situation ne semble pas inquiéter les contemporains, on ne saurait trop oublier que la clef des politiques de population est une action de nature préventive pour éviter que les pays, qui ne connaissent pas encore les difficultés d'adaptation avec leurs ressources, ne se trouvent demain dans la situation des pays aujourd'hui surpeuplés. Une saine politique n'est pas la science de ce qui est mais de ce qui doit être. Et cela peut amener à agir dans des sens que la logique commune réprouve. Par exemple, s'il est vrai que dans certains pays, notamment en Afrique, la fécondité est relativement basse en raison d'une forte stérilité, l'action doit consister à remédier à cette infécondité chez les couples stériles, mais

5. Une des hypothèses servant de toile de fond au Plan est qu'il existe un rapport dialectique, une sorte de va-et-vient entre facteurs démographiques et facteurs du développement, qui fait que toute modification de la population transforme simultanément les facteurs du développement et qu'inversement, toute transformation des conditions économiques et sociales modifie en même temps les comportements du point de vue démographique. Si le développement est une condition suffisante pour la modification de ces comportements, il n'en est pas cependant une condition nécessaire et il convient de passer d'une attitude *passive* qui consiste à considérer les variables démographiques comme des variables dépendantes du développement à une attitude *active* dans laquelle les variables démographiques sont capables de jouer un rôle pouvant influencer le développement.

6. La définition d'une politique adoptée dans ce Plan doit être entendue dans un sens large, quand bien même celui-ci est limité à six variables démographiques. Il s'agit de toute décision, toute mesure portant sur les paramètres démographiques qui, sur le plan quantitatif ou qualitatif, ont une influence sur le bien-être de la population, soit de façon directe soit de façon indirecte, c'est-à-dire incluant les effets secondaires des politiques économiques et sociales qui ont une influence sur les paramètres démographiques. Bien entendu, l'absence de toute action, le "laisser faire", est aussi une manière d'agir par abstention et est donc aussi une politique. Plus que dans bien d'autres domaines, le "laisser faire" est une prise de position qui oriente l'avenir. Les paramètres pris en compte ici, et développés dans la troisième partie du Plan, sont au nombre de six: la croissance démographique, la morbidité et la mortalité, la formation des familles et la fécondité, la migration intérieure, la migration internationale et, enfin, la structure par sexe et par âge. Ceci montre bien qu'il faut définitivement écarter l'idée, qui a longtemps prévalu, de limiter les politiques démographiques exclusivement à la régulation des naissances.

7. Le Plan tient compte de la très grande variété des situations entre les régions et dans les régions elles-mêmes. Les conditions sont entièrement différentes au Salvador, où les densités sont extrêmement élevées, qu'en Argentine, au Bouthan qu'au Bengladesh, en France qu'aux Pays-Bas. Dès lors, une très grande variété de politiques possibles doit être envisagée, selon l'ordre de priorité et d'importance que l'on accordera à telle action plutôt qu'à telle autre. La principale qualité d'un tel Plan est sa souplesse. Dans son application, certains mettront l'accent sur la régulation des naissances pour favoriser une fécondité plus humaine et plus rationnelle, pour soulager les pressions démographiques là où elles sont les plus fortes, d'autres sur la santé, comme c'est le cas notamment en Afrique, d'autres sur la répartition géographique et sur la migration interne ou internationale, comme c'est le cas en Argentine, ou sur plusieurs de ces facteurs. Cela représente autant de politiques différentes, voire opposées du point de vue de leurs conséquences sur la croissance. D'ailleurs, les recommendations du Plan ne sont pas solidaires les unes des autres, de même qu'un mécanisme d'horlogerie, ce qui doit permettre aux gouvernements de mettre l'accent sur telle ou telle autre action, et d'adopter des choix prioritaires qui peuvent difficilement être décidés à l'échelle internationale.

8. Le Plan reflète le souci grandissant de la justice sociale au niveau international. L'attention de la communauté internationale doit être à nouveau retenue par les couches les plus défavorisées, par ceux qu'on appelle indûment les marginaux, qui sont en fait majoritaires, à une époque où il n'est plus possible de se dérober à l'emprise des normes quasi-universelles de valeurs matérielles concernant certains besoins fondamentaux en matière de santé, d'alimentation, d'éducation, de plus en plus associées à des normes de comportement en matière de population. Il faut permettre aux catégories les plus pauvres

d'améliorer nettement et à brève échéance leur condition de vie et de combler progressivement l'écart qui les sépare des plus riches.

9. Dans l'adoption du Plan, il a été tenu compte des attitudes des gouvernements et celles-ci ne sont pas indépendantes des conditions matérielles de vie. Le Plan est en particulier fondé sur une analyse exhaustive (E/CONF/CBP/21) des déclarations des gouvernements à une enquête des Nations Unies, ou sur des déclarations officielles faites lors des conférences régionales des Nations Unies, comme de tout matériel jugé pertinent. Bien que l'étude ne puisse se placer dans une perspective dynamique, ce qui est regrettable étant donné les révisions d'attitude auxquelles nous n'avons cessé d'assister avec la préparation même de la Conférence, elle donne au moins une vue d'ensemble de la situation arrêtée en avril 1974. L'étude concerne 148 pays, soit la presque totalité du monde et 13 agences spécialisées des Nations Unies. Je vous en donnerai quelques résultats dans le cours de cet exposé.

10. Le Plan tient compte des systèmes de valeurs. Les problèmes de population sont, en effet, fortement liés aux systèmes de valeurs. Or, il est certain que les système de valeurs qui prédominent dans les pays industrialisés ne sont pas nécessairement les meilleurs pour le Tiers Monde. Certaines déceptions et certains échecs s'expliquent peut-être parce que, dans les instances internationales nous voyons trop souvent le Tiers Monde avec nos yeux alors que nous devrions le chercher tel qu'en lui-même il se voit, et pour cela être attentif à ses comportements.

La difficulté essentielle de ce Plan est d'être l'oeuvre de populations venant d'horizons culturels différents. Il a cependant été convenu qu'il était souhaitable de demander à chacun de faire abstraction de ses propres particularités et de rechercher à Bucarest un terrain d'entente valable pour tous. Nous avons gardé à l'esprit l'idée que l'accord doit l'emporter sur les réticences.

Voilà pour les principes. Quant aux objectifs, je pense qu'ils sont bien résumés dans le paragraphe 14 dans lequel il est dit que "le but primordial du Plan d'action est de doter les pays de moyens accrus et plus efficaces afin qu'ils soient mieux à même de résoudre leurs problèmes démographiques, nationaux ou régionaux, et de promouvoir une action internationale qui réponde à leurs besoins".

Un point délicat est celui de savoir si le Plan doit traduire ses objectifs en termes chiffrés et datés, ce qui aurait l'avantage, en plus de la clarté, de permettre dans les années à venir de suivre pas à pas la réalisation des buts que l'on s'est fixés. Est-il possible de résumer les intentions du Plan à quelques données chiffrées? Si oui, quelles variables devraient faire l'objet de cette quantification? Sur ce sujet, des divergences ont nettement été observées en raison, soit de la diversité des situations, soit de l'appréhension manifestée par certains que cette quantification ne conduise à un contrôle de l'action et ne porte ainsi atteinte au principe des souverainetés nationales. Je reviendrai sur ce problème à propos de chaque variable, mais je dois dire dès à présent que de nombreux pays, notamment dans le Tiers Monde, se sont déjà fixé des objectifs quantifiés notamment sur la croissance.

3 RECOMMANDATIONS SUR LES MESURE A PRENDRE

Ce recommandations se divisent en deux parties: celles qui concernent les politiques démographiques et celles qui se rapportent à l'amélioration des connaissances et à la promotion des politiques.

Les objectifs sur la croissance sont plutôt suggérés que réellement formulés. Il y est rappelé que selon les hypothèses basses des projections des Nations Unies, le taux d'accroissement en 1985 serait de 2,0% pour les pays en voie de développement, de 0,7% pour les pays développés et de 1,7% pour le monde. Cela correspond d'ailleurs assez bien aux objectifs que les pays se sont eux-mêmes fixés.

En fait, l'enquête auprès des gouvernements montre que déjà 42 pays considèrent leur taux de croissance comme "excessif", 21 "déficient" et 85 "acceptable", bien que ce dernier terme soit d'interprétation difficile, et est bien souvent lié à cette attitude de laisser-faire dont je parlais tout à l'heure, ou tout simplement au souci de ne pas exprimer officiellement une option quelconque. Mais ce qui est important, c'est que les pays de la première catégorie (taux "excessif") ont une taille moyenne double de la moyenne mondiale, de l'ordre de 50 millions d'habitants, et donnent ainsi l'impression de l'existence d'une "démographie d'échelle", les pays les plus peuplés du Tiers Monde étant aussi ceux où le taux d'accroissement est jugé le plus élevé. Ces pays représentent 57% de la population mondiale et 81% de la population du Tiers Monde. Il est également intéressant de noter que selon le découpage géographique des Nations Unies, l'Asie et l'Extrême-Orient ont le pourcentage le plus élevé, en terme de pays, dans la catégorie "excessif" (62% des pays représentant 90% de la population), l'Europe le pourcentage le plus élevé dans la catégorie "déficient"(23%) et l'Asie de l'Ouest, c'est-à-dire le Proche-Orient, dans la catégorie "acceptable". La corrélation entre ces trois catégories de perception du taux de croissance et du taux effectif de croissance n'est pas sans ambiguïté. C'est ainsi que le Brésil, avec un taux de l'ordre de 3,0, l'Algérie avec un taux un peu supérieur à 3%, Koweit avec un taux d'accroissement naturel de 3,5% et un taux réel de 10%, jugent leur croissance "acceptable" tandis que le Pakistan avec un taux de 2,4%, l'Inde avec un taux de 2,2% considèrent leur croissance "excessive".

Quoi qu'il en soit, le Plan invite les pays dont les taux de croissance font obstacle à la réalisation de leurs objectifs de développement, à le faire.

Pour ce qui touche la morbidité et la mortalité la question est beaucoup plus simple, car tous les gouvernements ont exprimé le souhait de la voir diminuer et placent souvent cet objectif en première priorité. Contrairement au taux de croissance, les désirs des gouvernements vont tous dans le même sens. Je rappelerai que dans 45 pays, qui représentent un tiers de la communauté mondiale, l'espérance de vie à la naissance n'atteint pas 50 ans et j'ajoute que des inquiétudes de plus en plus grandes se font jour dans ce domaine. Dans de nombreux pays européens, la mortalité a cessé de diminuer et montre même des signes de détérioration, surtout aux grands âges. Un ralentissement de la baisse de la mortalité semble apparaître dans le Tiers Monde.

L'espérance de vie à la naissance a augmenté de 20 ans en moyenne entre 1935–1939 et 1965–1970. Le projet du Plan est assez ambitieux. Il se donne pour objectif de faire passer cette espérance de vie moyenne dans les pays en voie de développement de 55 ans aujourd'hui à 62 ans en 1985 et à 74 ans en l'an 2000, ce qui représenterait une augmentation de 11 ans pour l'Amérique latine, de 17 ans pour l'Asie et de 28 ans pour l'Afrique dans l'intervalle des 26 années qui nous sépare de la fin du siècle. Je ne pense pas que nous puissions contester que l'attention doit porter sur la mortalité sociale, obscurcie par des chiffres moyens et par l'absence d'information qui devrait être l'un des sujets les plus préoccupants, étant l'une des manifestations les plus évidentes des injustices sociales.

Pour la formation des familles et la fécondité, les recommandations portent dans une première partie sur les mesures directes susceptibles d'influencer la formation des familles

et la fécondité, et dans une deuxième partie sur les mesures indirectes. L'action doit, en effet, consister non seulement à diffuser les moyens de régulation des naissances, avec tout ce que cela implique, mais encore, si l'on ne veut pas aller à l'échec, à agir de façon simultanée sur l'éducation, l'amélioration du statut de la femme, la diminution de la mortalité infantile, une fixation judicieuse de l'âge au mariage etc. Le but essentiel de ces motivations est de créer des conditions favorables à l'émergence ou au renforcement des motivations par une parenté responsable, écartant toute idée de coercision. Il s'agit de favoriser des "structures d'accueil" facilitant un changement du comportement procréateur.

Le projet ne discute pas les techniques de régulation des naissances. Il ne s'est, en particulier, pas prononcé sur la stérilisation comme sur l'avortement, quand bien même le cheminement des idées dans ce domaine soit très rapide. Je rappelle que la stérilisation est légale dans 24 pays. L'avortement pour des motifs sociaux ou médicaux, et sur simple demande de la femme est déjà légal dans 35 pays, et certains vont même jusqu'à la gratuité des soins. Seuls sept pays, tous asiatiques, justifient explicitement l'avortement comme moyen de régulation des naissances et pas seulement pour le bien-être familial, la santé de la mère, le statut de la femme.

Au paragraphe 36, il est indiqué que si les projections basses des Nations Unies sont effectivement réalisées en 1985 (para. 16) et si les objectifs formulés dans ce projet en matière de mortalité (para. 22) étaient réalisés d'ici à 1985, le taux moyen de natalité, qui est actuellement de 38 pour mille, tomberait à 30, alors que les projections prévoient 34 pour mille. Si l'on veut faire "mieux" que les projections et atteindre les buts que l'on s'est fixés, des efforts considérables doivent être dès maintenant déployés pour faire baisser les taux de natalité là où on le juge nécessaire.

La Conférence a rejeté un paragraphe du Plan, dans lequel il était dit que les pays où les taux de natalité sont très élevés pourront envisager de prendre des mesures afin de réduire ces taux de 5 à 10 pour mille environ avant 1985.

La Conférence a également refusé d'inclure la date de 1985 dans un paragraphe où il était stipulé que "les pays sont invités instamment à mettre à la portée des personnes intéressées, si possible avant la fin de la Deuxième Décennie des Nations Unies et au plus tard en 1985, l'information et les moyens d'éducation nécessaires en matière de planification de la famille".

Dans l'enquête auprès des gouvernements, quatre catégories d'attitudes ont été distinguées pour ce qui concerne la diffusion des moyens et des services sur la régulation des naissances: la première qualifiée de "restrictive", la seconde de "tolérante", la troisième de "favorable" et la quatrième de "soutien officiel" c'est-à-dire au moyen surtout de subventions à des institutions publiques ou privées. Nous constatons que 8 pays seulement, représentant 2% de la population mondiale, appartiennent à la première catégorie. Tous les autres pays tolèrent au moins la contraception et 50%, représentant 81% de la population du monde, se situent dans la quatrième catégorie, c'est-à-dire d'un soutien actif dépassant le simple libéralisme. On trouve naturellement dans cette catégorie 88% des gouvernements qui perçoivent leut fécondité "excessive", mais aussi 50% de ceux qui considèrent leur fécondité "déficiente".

Les recommandations sur la répartition géographique des populations et la migration intérieure portent sur trois points essentiels: la régulation des mouvements, le droit à la migration et l'intégration des mouvements migratoires aux plans et programmes de développement économique et social, ce qui implique une double politique de réanimation rurale et d'aménagement des espaces urbains. Il est intéressant de noter que les informations

recueillies auprès des gouvernements indiquent qu'en majorité, ceux-ci perçoivent le processus d'urbanisation comme une manifestation inéluctable et positive du développement et de la modernisation. Cependant, peu de gouvernements adoptent des mesures visant à encourager les courants migratoires vers les très grandes agglomérations et 76 ont même déjà pris des mesures tendant à les détourner.

Trois sortes de migrations internationales ont été considérées: migrations de travailleurs non qualifiés ou faiblement qualifiés, les réfugiés politiques et l'exode des cerveaux. Les recommandations portent sur le droit à la migration, la protection du migrant et de sa famille, le rôle des organisations internationales pour la conclusion des accords bilatéraux ou multilatéraux réglementant les mouvements migratoires.

En fait, les informations recueillies sur les politiques relatives aux migrations internationales indiquent clairement que les gouvernements sont très préoccupés par cette composante du mouvement de la population, non seulement pour ce qui a trait à la surveillance administrative des mouvements, mais aussi pour ce qui concerne la composition et la croissance de la population active. Si 76 pays autorisent ou encouragent l'émigration permanente et 96 l'émigration temporaire, 32 pays seulement encouragent l'immigration permanente et 36 l'immigration temporaire. Comme on peut s'y attendre la grande majorité des pays qui encouragent l'immigration est située en Europe, au Moyen-Orient, en Australie et sur le continent américain. Mais c'est un domaine où l'influence des caprices de la conjoncture est très grande et des retournements d'attitude sont souvent observés en fonction de l'évolution économique générale.

De nombreuses recommandations portent ensuite sur l'amélioration des connaissances en matière de population, qu'il s'agisse du rassemblement et de l'analyse des données, de la recherche, de la formation multidisciplinaire, de l'information du public. Tous ces points sont d'une importance fondamentale car il est biené vident qu'une politique qui ne serait pas fondée sur un solide plan de réflexion serait immanquablement vouée à l'échec. Il faut trouver l'outil adéquat si l'on veut mettre en accord les principes contenus dans le Plan et son application.

4. RECOMMANDATIONS POUR L'APPLICATION DU PLAN

Enfin, la dernière partie du projet porte sur le rôle primordial des gouvernements, celui de la coopération internationale, l'observation et l'évaluation du Plan.

Qu'il me soit permis d'insister sur deux points mentionnés au paragraphe 85, à savoir deux principes devant guider la contribution des organisations internationales: celle-ci ne saurait intervenir qu'à la demande expresse des gouvernements et les ressources financières mises à la disposition de ces gouvernements doivent s'ajouter aux autres sources d'aide économique.

Le document présente d'une manière claire un texte pouvant inspirer le politique et le praticien en enrichissant leur imagination, en les aidant à se poser les bonnes, les vraies questions, en leur fournissant des suggestions, voire des prescriptions. Il permet de faire entrer dans le champ du possible ce qui paraît nécessaire à la communauté internationale.

Demain ce ne sera plus le "pourquoi" qui va nous requérir mais le "comment". Cela va exiger un effort considérable d'organisation au niveau national comme au niveau international pendant de longues années.

Dès la fin de cette année, des réunions régionales vont se tenir pour mettre en oeuvre le Plan en l'adaptant aux conditions de chaque région.

CONCLUSIONS GÉNÉRALES DE LA CONFÉRENCE MONDIALE "VERS UN PLAN D'ACTIONS POUR L'HUMANITE"

COULOMB: Je prie maintenant un représentant de chacun des cinq groupes réunis pendant notre conférence, de bien vouloir prendre place auprès de moi: je leur donnerai successivement la parole. Chacun d'entre eux indiquera les conclusions auxquelles sont parvenus les membres de son groupe. Ces conclusions sont quelquefois assez complexes et nous ne pourrons pas les discuter en détail. Elles seront alors considérées comme des conclusions du groupe et non pas comme des conclusions de la conférence. Mais, après chacun des cinq rapports, nous choisirons un ou deux points particulièrement importants et nous les mettrons en réserve. Lorsque les cinq rapports auront été présentés, nous ouvrirons une discussion sur les cinq ou six points retenus. Leur examen se terminera à six heures. Il faut, en effet, que nous gardions une demi-heure pour considérer les propositions dont l'initiative pourrait être prise par des membres de l'assemblée. Une telle discussion finale, plus libre, ne pourra cependant pas être tout à fait générale et reprendre tout ce qui a été soumis à la conférence, mais devra porter sur des textes aussi précis que possible. Je donne donc la parole à Monsieur Malinvaud qui est le premier à parler puisqu'il représente le groupe des Economistes.

MALINVAUD: Le groupe des économistes qui s'est réuni à la Conférence mondiale de l'Institut de la Vie exprime ses conclusions comme suit:

1. Les choix ouverts au développement à long terme de l'humanité dépendent de ce que sont les réserves en ressources naturelles, de ce que seront les progrès techniques dans la mise en oeuvre de nouvelles productions, enfin des lois qui régissent la transformation des équilibres biologiques et écologiques. Sur ces diverses conditions de la croissance future les connaissances scientifiques actuelles laissent subsister de très grandes marges d'incertitude.
2. Le risque semble exister que l'économie mondiale voit dans l'avenir s'accuser des raretés de natures diverses et qu'ainsi les conditions du développement subissent une mutation par rapport au dernier siècle écoulé au cours duquel, du fait du progrès scientifique et technique, les raretés ont eu dans l'ensemble tendance à diminuer.
3. Devant ce risque, on peut recommander qu'une politique prudente soit adoptée pour la natalité, la gestion des ressources et la préservation de l'environnement. On ne sait pas si ceci requiert un ralentissement substantiel du taux de croissance de la production mondiale. Comme un tel ralentissement aurait des conséquences lourdes, particulièrement pour les pays pauvres, il serait prématuré de la proposer. Les choix économiques doivent cependant privilégier, plus que par le passé, la qualité de la vie et peuvent avoir pour conséquence un ralentissement dans le rythme de croissance de la consommation de produits manufacturés, tout au moins dans les pays déjà industrialisés.
4. Pour prendre correctement en considération les exigences du long terme et faciliter des adaptations rapides, la gestion des ressources doit savoir combiner le fonctionnement des marchés et l'utilisation des prix à la planification aux niveaux local, national et international. La meilleure combinaison de ces instruments ne doit pas résulter d'une préférence dogmatique mais d'un examen particulier de chaque cas. Il est clair, cependant, que seront nécessaires des institutions nouvelles, ou plus efficaces, de planification sociale.
5. Les problèmes d'équilibre entre ressources et besoins risquent de se poser beaucoup moins à l'échelle du monde considéré comme un tout que dans certaines régions en voie de développement. La politique de croissance des autres régions doit être conçue en tenant compte de ses conséquences sur les régions critiques qui peuvent avoir besoin de débouchés, de capitaux et de dons en nature. Le ralentissement éventuel de l'expansion industrielle des pays développés ne doit pas être supporté par les pays pauvres.
6. Les progrès de la conscience et la solidarité accrue entre les hommes de la planète imposent plus généralement que la distribution des biens devienne plus équitable à l'intérieur de chaque pays et entre les pays. Pour atteindre ces objectifs, on devrait d'ailleurs faire comprendre aux citoyens des diverses nations que leur intérêt à long terme recommande l'aide aux pauvres, notamment à ceux du monde en voie de développement.
7. Nous insistons auprès des économistes pour que, en coopération avec leurs collègues des autres sciences, ils intensifient leurs efforts pour comprendre et prévoir les implications de la croissance de la population comme celles de l'éventuel renforcement des raretés touchant les ressources physiques et l'énergie. Il faut d'une part des études factuelles sur la demande et l'offre des matières critiques, d'autre part des réflexions sur le fonctionnement des institutions et la transformation souhaitable de l'organisation économique.

COULOMB: Je pense que nous pourrions retenir deux idées dans votre exposé pour la discussion qui aura lieu tout à l'heure: tout d'abord le troisième point des économistes, c'est-à-dire les recommandations de prudence dans la gestion des ressources et l'idée de privilégier la qualité de la vie, même s'il faut ralentir la consommation; d'autre part, le point 5 c'est-à-dire l'accent mis sur les politiques régionales, ou encore l'idée qu'il faut se préoccuper de la redistribution des ressources, avant de se préoccuper de la croissance globale. Je vais maintenant passer la parole au Professeur Brown pour nous parler des résolutions prises par le groupe qui s'est occupé des ressources minérales.

BROWN: 1. The rate of growth of resource consumption in the industrialized countries should be decreased. A number of approaches to this goal are possible including increasing the lifetimes of manufactured goods, minimizing their contents of valuable raw materials, and designing them so they can be recycled or otherwise utilized efficiently from the points of view of energetics and the environment.

2. The economic growth of the developing countries should be accelerated as rapidly as possible with the objective of eliminating poverty and misery.

3. The rate of population growth worldwide cannot go on increasing, recognizing that the level of decrease which is both desired and attainable varies considerably from nation to nation, depending upon the resource base culture and economic development.

4. National and international bodies should encourage actions which will help discover new resources or extend already known sites, especially through research on better methods for prospecting and evaluating deposits for extracting and concentrating minerals.

All of these actions should be complemented by studies of how to integrate exploitation, how to use raw materials more rationally, and how to recover wastes more efficiently. They should also take into account the protection of other resources.

5. It is important to conduct geoeconomic analyses in different countries, integrating reserves and resources, their social and economic development and demographic prospects. On the basis of these analyses, multinational plans for rational use and management of resources can be drawn.

6. With respect to the recycling of wastes, legislative and economic incentives are needed to control the production of wastes, to encourage recycling, and to develop markets for recycled products.

7. National and international bodies should take steps to increase the quantity and quality of research dealing with the handling and recycling of waste products.

Traduction française:

1. Le taux de croissance de la consommation des ressources dans les pays industrialisés devrait être réduit. Plusieurs possibilités s'offrent pour atteindre ce but, parmi lesquelles l'allongement de la durée de vie des biens manufacturés, la réduction au minimum de leur contenu en matières premières précieuses et le choix d'une conception qui permette un recyclage ou une réutilisation efficace du point de vue énergétique et de l'environnement.

2. La croissance économique des pays en voie de développement devrait être accélérée aussi rapidement quei possible en vue d'éliminer la pauvreté et la misère.

3. Le taux de croissance global de la population mondiale ne peut pas continuer à croître, toutefois le degré de diminution de ce taux de croissance varie considérablement selon les pays, compte tenu de leurs ressources, de leur culture et de leur développement économique.

4. Les organismes nationaux et internationaux devraient encourager les actions pour aider à la découverte de nouvelles ressources ou à l'extension des gîtes déjà reconnus, en particulier par des recherches permettant d'améliorer les méthodes de prospection et d'évaluation des gisements, ainsi que les procédés d'extraction et de valorisation des minerais. Toutes ces actions devraient être complétées par des études portant sur une exploitation intégrée, une utilisation plus rationnelle des matières premières et une récupération accrue des déchets. Elles devraient également tenir compte de la protection des autres ressources.

5. Il est important de procéder à des analyses géoéconomiques dans différents pays en intégrant les réserves et les ressources, le développement économique et social et les perspectives démographiques. Ainsi pourront être établis des scénarios plurinationaux d'utilisation et de gestion rationnelles des ressources.

6. En ce qui concerne le recyclage des déchets, des mesures législatives et économiques sont nécessaires pour limiter la production des déchets, encourager leur recyclage et développer les marchés des produits recyclés.

7. Les organismes nationaux et internationaux devraient prendre des mesures pour augmenter le nombre et améliorer la qualité des recherches sur les méthodes de traitement et de recyclage des déchets.

COULOMB: Je retiens cette fois les idées suivantes: le groupe des ressources minérales propose de faire décroître la consommation des ressources dans les pays industrialisés, et de l'accélérer dans les pays en voie de développement; ce sera notre troisième point. Il est d'ailleurs en relation évidente et très étroite avec le premier point retenu tout à l'heure: la prudence recommandée par les économistes dans la gestion des ressources avec priorité à la qualité de la vie et au ralentissement de la consommation. Les deux idées pourront être discutées en même temps. Nous passons maintenant au troisième groupe, qui s'est préoccupé des ressources en énergie, et je donne la parole à Monsieur Gibrat qui veut bien le représenter.

GIBRAT: Le groupe des spécialistes de l'énergie est conscient des dangers graves à court terme qui menacent l'humanité à la suite de l'augmentation des prix des produits pétroliers, mais il estime que ces dangers relèvent de la politique, et non de nouvelles sources ou techniques.

Il est assuré de la nécessité absolue de permettre aux pays eu cours de développement l'élévation du niveau de vie et est persuadé que l'énergie en est un facteur essentiel.

Il croit que, dans les pays industrialisés, l'augmentation des prix des combustibles modifiant la répartition et les calculs d'optimisation, une certaine saturation des besoins et une participation plus importante d'in-

dustries ou services à consommation faible d'énergie amèneront automatiquement un ralentissement de la demande d'énergie.

Il estime donc que la consommation mondiale énergétique en l'an 2000 ne dépassera pas deux ou trois fois la consommation actuelle et que, dans ces conditions, il n'y a pas à craindre à moyen ou à long terme de pénurie d'énergie.

Il considère que les problèmes d'environnement à cette échelle paraissent solubles, mais que la prolifération possible au XXIème siècle des surgénérateurs posera, avec le plutonium, des problèmes dont il faut mettre au point la solution. Il est donc nécessaire dès maintenant de préparer l'avènement de sources nouvelles: énergie solaire, géothermique ou de fusion. De mêmes les incidences climatologiques pourront à cette époque être préoccupants.

Il recommande donc:

1. La poursuite des efforts sur les surgénérateurs et les réacteurs à haute température, l'intensification des études sur la production d'hydrogène à bas prix.
2. Un nouvel examen des sources d'énergie disponibles, gazéification et liquéfaction du charbon, énergie marémotrice ou énergie thermique des mers.
3. L'intensification des recherches actuelles sur l'énergie solaire, l'énergie géothermique et la fusion nucléaire.

English translation:

The group of experts in energy is conscious of the severe short term dangers which menace mankind following the increase of mineral oil products costs, but they deem that these dangers are dependent on political measures and not on new sources or techniques.

They are convinced of the absolute necessity for the countries under development to be given access to an honorable form of civilization and they are sure that energy is an essential factor.

They believe that, in the industrialized countries, the optimum of repartitions being modified by the increased cost of fuels, the needs in energy will automatically slow down due to some saturation of the needs and a larger participation of industries or services with low energy consumption.

Consequently, they estimate that the world energy consumption in the year 2000 will not go beyond two to three times the current consumption and that, under these circumstances, no mean or long term scarcity is to be feared.

They consider that the problems of environment seem to be solvable at this scale, but that the possible proliferation of breeders during the twenty-first century will set a problem with plutonium, to which a solution is difficult to foresee. Therefore, it is necessary to prepare from now onward the advent of new sources, solar, geothermal or fusion. By then, also, climatological problems may become of some concern.

So they recommend:

1. Further efforts on breeders and high temperature reactors; the intensification of studies on low cost hydrogen production.
2. A new review of the available energy sources, coal gasification, and liquefaction, sea tidal or thermal energy.
3. The intensification of current efforts on solar energy, geothermal energy, and nuclear fusion.

COULOMB: Il me semble que, dans ces résolutions, très importantes et très détaillées du groupe de l'énergie, nous pouvons retenir une suggestion globale: ce groupe réclame un grand effort pour l'étude de solutions nouvelles aux problèmes de production d'énergie. C'est une idée qui pourra probablement susciter un consensus plus facilement que certaines des précédentes. Je donne maintenant la parole au Professeur Tarzwell, pour nous indiquer l'opinion du groupe qui s'est occupé de la pollution, en particulier de la pollution thermique.

TARZWELL: In putting together our recommendations we found that it was difficult to consider thermal modification and biological balance without taking into consideration other types and forms of pollution. The recommendations of our group on biological balance and thermal modifications are as follows:

1. The group "Biological balance and thermal modifications" recommends that steps be taken for overall land and water management. As a first step it is recommended that planning for wise usage of land and water be undertaken, including designation of best usage such as agricultural, urban, industrial, recreational, nature conservancy, etc.

2. The group recommends that research be carried out for the determination of air and water quality requirements for their various uses, so that data be available for the establishments of air and water quality standards and effluents requirements.

3. The group points out that the problems of pollution, particularly thermal pollution, can be solved, but only with a worldwide increase in public and legislative awareness and with the granting of priority in the process of allocating the financial resources.

4. The group points out that energy conservation measures and the search for alternative energy sources have strong environmental implications. As a basic criterium, the group recommends that a least energy use pathway be followed to meet any legitimate society need, since such a pathway will result in minimizing environmental effects.

5. The group recommends strongly that research be conducted to develop thermoelectric plant designs such that adverse environmental effects such as thermal, toxic pollution, and mechanical damages, etc., are minimized or eliminated. It is necessary to select in advance sites for thermoelectric plants where detrimental environmental effects will be at a minimum and require that all new plants be located in one of these sites. Estuaries, rivers with low dilution capability, shallow lakes and marine embayments with poor circulation are recognized as being extremely vulnerable, especially in tropical regions.

6. The group recommends that all operations such as lumbering, grazing agricultural practices, mining, road building, drainage and construction of dams be carried out in such a way as to minimize all adverse environmental effects such as soil erosion, flooding, destruction of vegetation cover, reduction of carrying and production capacity, increased surface runoff and decreased low water plan, damage to the environment of continental shelves, etc.

7. The group considers it essential to achieve a high degree of cooperation among the various scientific and engineering disciplines involved in basic research, applied investigations, overall planning and detailed design of facilities affecting the environment.

Environmental and pollution problems must now be considered on a global scale.

Traduction française:

1. Le groupe "Modifications thermiques et équilibres biologiques" de la conférence mondiale de 'Institut de la Vie recommande que des mesures soient prises pour un aménagement d'ensemble des espaces naturels et des eaux. Dans un premier temps, il est recommandé d'établir un plan rationnel d'affectation des espaces et des eaux prévoyant leur utilisation optimale en fonction des divers besoins de l'homme: agriculture, urbanisation, industrie, loisirs, conservation de la nature, etc.

2. Le groupe recommande que soient entreprises des recherches permettant d'établir les critères de qualité de l'air et des eaux correspondant aux différentes utilisations, de façon à disposer des données nécessaires à l'établissement de normes de qualité de l'air et des eaux ainsi que des contraintes à appliquer aux rejets.

3. Le groupe souligne que les problèmes de pollution, et particulièrement de pollution thermique, peuvent être résolus, à la condition expresse que le public comme les autorités prennent conscience de leur importance et que les priorités nécessaires leur soient reconnues dans l'allocation des ressources financières.

4. Le groupe souligne que les mesures visant à assurer une utilisation optimale des énergies existantes et les efforts pour développer des sources nouvelles d'énergie ont d'importantes conséquences sur l'environnement. Aussi recommande -t-il que soit reconnue la nécessité d'utiliser les quantités minimales d'énergie compatibles avec les besoins de la société, ce qui conduira à minorer les effets sur l'environnement.

5. Le groupe recommande avec la plus vive insistance:
   - d'une part que soient effectuées des recherches visant à ce que les installations thermoélectriques soient conçues de façon à minimiser ou éliminer les dommages à l'environnement résultant des effets thermiques, toxiques ou mécaniques;
   - d'autre part, que soit établi un inventaire des sites potentiels d'installations thermoélectriques correspondant à un minimum d'agressions vis-à-vis de l'environnement et que les nouvelles centrales soient impérativement implantées dans l'un de ces sites.

Les estuaires, rivières à faible potentiel de dilution, lacs peu profonds et baies maritimes à circulation déficiente, doivent être considérés comme particulèrement vulnérables, principalement dans les régions tropicales.

6. Le groupe recommande que diverses activités humaines telles que l'exploitation forestière, le pâturage, les exploitations minières, la construction des routes, les opérations de drainage, les constructions de barrages soient conçues de façon à minimiser les conséquences de ces activités sur l'environnement et notamment: l'érosion, les inondations, la destruction du couvert végétal, la réduction des possibilités d'élevage de bétail, l'accroissement du ruissellement, la diminution du débit d'étiage des fleuves, l'altération des eaux et des fonds du plateau continental.

7. Le groupe considère qu'il est essentiel de parvenir à une étroite coopération entre les diverses disciplines scientifiques et celles de l'art de l'ingénieur, disciplines qui sont toutes concernées dans les recherches fondamentales et appliquées, la planification générale et la conception détaillée des installations susceptibles d'affecter l'environnement.

Les problèmes d'environnement et de pollution sont devenus des problèmes qu'il faut considérer à l'échelle du globe.

COULOMB: Il me semble que l'idée sur laquelle nous pourrons discuter utilement tout à l'heure est la première et dernière—vous l'avez rappelée à la fin—c'est le plan d'aménagement global pour les espaces naturels et pour les eaux. Je suppose que ce plan doit être établi d'abord à l'échelle nationale, mais peut-être ensuite à l'échelle internationale. Votre groupe met avec raison, me semble-t-il, l'accent sur cette cohérence entre la protection des différents espaces naturels et des eaux contre la pollution. C'est le point que nous pouvons peut-être discuter utilement tout à l'heure. Je donne enfin la parole à Monsieur Davous qui va nous indiquer les résolutions du groupe de travail sur l'analyse des systèmes et la modélisation.

DAVOUS: 1. Les participants du groupe "La modélisation des systèmes mondiaux et ses limites" expriment leur gratitude à L'Institut de la Vie qui a rendu possibles des échanges d'informations et de points de vue entre des hommes concernés ou intéressés par le développement de la modélisation des systèmes globaux.

2. Les modèles ont un rôle à jouer dans l'étude de nombreux aspects des processus de développement mondial, car la plupart de ces problèmes présentent une ou plusieurs des caractéristiques suivantes:

— complexité
— haut degré d'interconnection et nature interdisciplinaire
— nature quantitative.

Le besoin de modèles a été exprimé par d'autres groupes pendant la conférence.

3. Nous sommes au stade initial des développements de grands modèles sur ordinateurs et les utilisateurs potentiels de tels modèles doivent être conscients des faits suivants:

a) la difficulté dans la modélisation augmente quand on passe des systèmes physiques aux systèmes biologiques et bien davantage encore quand on atteint le niveau des systèmes humains.
b) Pour les systèmes non physiques, il est prématuré ou peut-être même impossible d'utiliser une approche d'optimisation, c'est-à-dire telle que l'action optimale se trouve définie de façon automatique. La modélisation semble très utile actuellement pour une évaluation partielle des conséquences possibles de diverses séries de décision; au décideur d'exercer son jugement.
c) L'interaction entre les différents partenaires qui influencent l'activité de modélisation est un processus complexe. La qualité du modèle qui en résulte sera améliorée si on attache suffisamment d'attention aux différences dans les buts, les perceptions, les perspectives de temps, la nature de l'intérêt, les rôles et les responsabilités des hommes du monde politique et de l'administration, des groupes de planification, des hommes d'affaires, des constructeurs de modèles, des universitaires et autres intellectuels, et du public tout entier.
d) il existe un autre type d'interaction à l'intérieur même de l'activité de modélisation entre les spécialistes de disciplines différentes impliqués dans le projet.
Comme nous ne savons pas encore comment diriger une équipe pluridisciplinaire, il faut être spécialement attentif à obtenir la meilleure contribution des diverses disciplines.

L'interaction homme-machine qui fait partie de l'activité de modélisation soulève d'autres problèmes, mais fait aussi apparaître d'autres opportunités, car les systèmes d'interaction homme-machine seront sans doute au coeur de nombreuses activités de modélisation.

4. En dépit de ces limites, il est urgent de faire progresser la modélisation globale dans les voies suivantes:

a) les activités de modélisation doivent être encouragées à la fois en tant que développement scientifique et en tant que contribution directe à la solution de certains problèmes importants.
b) il ne faudrait pas définir une seule voie. Il convient d'encourager une exploration profonde des diverses avenues qui s'ouvent aujourd'hui.
c) un effort continu doit être entrepris en vue d'analyser et de comparer les divers modèles et de s'assurer de leur validité en fonction d'un certain nombre de données statistiques. Parallèlement, il conviendrait d'évaluer en permanence les hypothèses et les processus qui caractérisent les divers modèles.
d) un flot continu d'informations devrait s'établir entre ceux qui conçoivent le modèle et les autres partenaires qui sont ou devraient être impliqués dans l'application du modèle.
Des efforts de vulgarisation et d'éducation du public devraient être entrepris, mais en prenant bien garde d'éviter tout optimisme ou pessimisme illégitime.
e) la coopération internationale est essentielle dans les domaines suivants:

— échange des données statistiques
— mise en commun des ressources intellectuelles
— éventuelle mise en commun de quelques outils tels les ordinateurs.

Cette coopération rendra nécessaire un organisme international de coordination. On peut encore discuter sur la nature exacte de cet organisme international, mais son existence semble hautement désirable.

5. Il faut engager la discussion avec les membres d'autres disciplines qui participent au congrès pour identifier les domaines où la modélisation peut être utile et où des actions à court terme pourront être conduites.

English translation:

1. The participants express their gratitude to the Institut de la Vie, who have made possible these exchanges of information and of points of view between people involved in and interested by the development of global system models. This conference has been an excellent step which will hopefully be followed by others.

2. Models have a role to play in the study of many aspects of world development processes because most of these problems have one or more of the following characteristics:

— complexity,
— interconnectedness and interdisciplinary nature,
— quantitative nature.

Needs for models have been expressed by other groups during the conference.

3. We are at an early stage of developing large computer models, and the potential users of such models should be made aware that:

(a) There are increasing difficulties in model building when we go from physical systems to biological systems and still more to the level of human systems.
(b) For nonphysical systems it is too soon or maybe impossible to use an optimization approach (where the optimal course of action should be generated automatically). Modeling seems to be most useful at the present stage for a partial assessment of the possible outcomes resulting from various sets of decisions; this array of possibilities can illuminate the problem under study and enable the decision maker to exercize his judgment.
(c) The interaction between the various people influencing a model building activity is a complex process. The quality of the resulting model will be improved if sufficient attention is paid to the differences in goals, perceptions, time horizons, interests, responsibilities and accountability of the politicians, the administrators, the planning groups, the businessmen, the model builders, academics, and other scholars and the public as a whole.
(d) Another type of interaction occurs, within the model building activity, between the specialists of the various disciplines involved in the project. As we do not know yet how to manage efficiently a multidisciplinary team, special care has to be exercised to insure the best contribution from the various disciplines. Man-machine interaction, which is part of the modeling activity, brings other problems, but also new challenges, because interactive man-machine systems will probably beat the core of many modeling activities.

4. In spite of these limitations, global modeling is to be promoted urgently along the following lines:

(a) Modeling activities are to be encouraged both as a scientific development and as a direct contribution to the handling of some problems which are relevant and capable at the moment of being dealt with by this approach.
(b) No single route should be specified, and a deeper exploration of the various roads open at present is to be encouraged.
(c) A continuous effort should be launched, with a view to analysing and comparing the various models and ensuring their validation on a variety of statistical bases. In parallel, a continuous assessment should be made of the foundations and of the processes on which the various models are based.
(d) A continuous flow of information should be established between the model designers and the other people who are (or should be) involved in the application of the model. Efforts at popularization and public education should be undertaken, but with a great care to discourage undue optimism and pessimism.
(e) International cooperation is essential on:

— exchange of statistical data,
— pooling of intellectual resources,
— possible pooling of some tools (computers).

This will induce a need for an international coordination body. The exact nature of this international body is still open to discussion, but its existence seems to be highly desirable.

5. A discussion should be immediately opened with the members of the other disciplines attending the congress, in order to identify areas where modeling can help, and to select some short term actions which should be undertaken.

COULOMB: Ainsi s'achève la revue des travaux accomplis par nos cinq groupes de travail, et je vais vous rappeler les points qui nous ont paru les plus saillants, et sur lesquels je vais ensuite ouvrir la discussion.

Du point de vue des économistes, nous avons retenu deux idées. La première c'est d'être prudent dans la gestion des ressources, et corrélativement de privilégier la qualité de la vie, même s'il faut ralentir la consommation. Suivant la deuxième idée, l'on doit se préoccuper de la redistribution des ressources, plutôt que de la croissance globale.

Sur les ressources minérales, nous avons retenu la proposition, assez révolutionnaire, de faire décroître la consommation dans les pays industrialisés; par contre on accélèrerait sa croissance dans les pays en voie de développement; cette contrepartie n'était pas elle-même révolutionnaire.

Le groupe des ressources énergétiques réclame un grand effort pour l'étude des solutions nouvelles au problème de production d'énergie.

Le groupe de la pollution, demande un plan d'aménagement d'ensemble pour les espaces naturels et les eaux. Enfin le groupe de la modélisation suggère une promotion de la coopération internationale pour l'échange des données statistiques, la mise en commun des ressources intellectuelles, et si possible, la mise en commun des moyens de calcul.

Je vais maintenant ouvrir la discussion sur l'ensemble de ces six points. Ils ne sont pas rigoureusement indépendants et ne peuvent guère être discutés l'un après l'autre. Ce que je demanderais, c'est que les orateurs soient brefs, et qu'ils essayent de présenter des propositions précises. Je donne la parole, pour commencer, au Professeur Stewart.

STEWART: It seems to me that you have retained from the economists, the materials people, and from the energy group, papers which have a great deal in common. I believe that the strength of what we have to say would be much greater if these statements were combined in some way.

There is another question which I would like to ask of the gentleman involved and as the group as a whole: We have had considerable emphasis on the concept of a reduction of the rate of growth within the developed countries. I would believe that the intention was that the reduction should be in the rate of growth of material products—not necessarily a reduction in the rate of growth even of such a bad indicator as the gross national product, and certainly not necessarily a reduction of the growth of some better figure of merit for the quality of life within a society. Am I right in this assumption?

BROWN: With respect to the consumption of resources we recommended that the rate of growth of resource consumption be decreased. There are many approaches to this. One of them is the actual rate of growth of consumption of items. I think that this might be debated by the economists. I am not sure. The other is making more efficient use of the resources that we do use and making sure that they are designed in such a way that they can be recycled and that recycling techniques are developed as much as possible. I am quite sure that energy can be linked directly with this because a decrease in the rate of growth of resource consumption has directly connected with it a decrease in the rate of growth of energy consumption to the extent that energy consumption is used in this way.

LINDBECK: To avoid misunderstandings I want to emphasize that, as far as I understand, the group of economists has not recommended as a target for policy to reduce the growth rate of either gross national product or consumption. What is said is the following: we recommend a reallocation of resources in the economy in favor of things that improve the quality of life and the environment, and we expect that one *result* of this *may* be that the growth rate of consumption will fall. That is the issue. It is important to note here that the recommendation is *not* to reduce growth as a target, but to reallocate resources in favor of an improvement of the environment, even though these reallocations might result in a fall in the growth rate of consumption in the rich countries.

BROWN: Our recommendations of our two groups are different in this respect. I would like to stress that the resources group specifically recommends a decrease in the rate of growth of resource consumption. As we stressed again and again, the time scale for the bringing into existence of new resources is a long one and not a short one.

MALINVAUD: Je ne crois pas qu'il y ait de désaccord entre le groupe des Economistes et le Professeur Harrison Brown sur ce dernier point. Nous avons entendu exprimer la même idée en disant qu'il fallait adopter une politique prudente pour la gestion des ressources. Peut-être ce terme de gestion des ressources est-il imprécis, mais il concerne en particulier le rythme auquel nous puisons dans les ressources naturelles. L'idée de ralentissement de la consommation de ressources minérales, ou énérgétiques, est conforme à la recommandation d'une politique prudente, à supposer que, préalablement, la politique n'était pas prudente.

COULOMB: Je donne maintenant la parole à M. Ben Mena.

BEN MENA: J'appartiens au groupe sur les ressources énergétiques. J'ai beaucoup apprécié votre choix des différentes recommandations, mais puis-je me permettre de faire une petite remarque concernant la recommandation du groupe "ressources énergétiques" pour être cohérent avec les recommandations qui ont été faites par les autres groupes? Le groupe de l'économie nous a parlé de la prudence de la gestion des ressources, le groupe des ressources minérales a aussi mis l'accent sur un certain ralentissement de la consommation. Est-il possible, pour le groupe des ressources énergétiques, d'introduire, en plus de l'effort pour trouver des solutions nouvelles de production d'énergie, une idée qui insisterait sur une sorte d'optimisation de l'utilisation des ressources énergétiques actuelles?

COULOMB: Monsieur Gibrat, voulez-vous répondre à cette question?

GIBRAT: Il est évident que l'étude des sources nouvelles ne devant apporter de résultat, à l'échelle mondiale, que dans les premières décennies du 21ème siècle, ne peut pas être en relation avec l'optimisation des ressources actuelles. Celles-ci auront, évidemment, profondément changé, à cette époque. D'autre part, dans notre recommandation d'ensemble, (et je réponds là à la fois à tous les orateurs précédents) nous n'avons pas porté de jugement sur l'intérêt, ou non, de la consommation d'énergie, nous avons voulu attirer l'attention sur ce qui paraît peu connu à savoir que, d'une façon quasi automatique, par suite de la remise en ordre des prix des combustibles, nous allons assister à la création de freins de cette consommation d'énergie, dont le premier est celui dont vient de parler Monsieur Ben Mena, c'est-à-dire une nouvelle optimisation des ressources. On sera conduit à isoler plus fortement les maisons, l'équilibre entre investissement et consommation d'énergie ayant changé, et ceci n'est qu'un exemple, mais qui peut conduire, après l'inertie habituelle à ces problèmes, à une diminution de la moitié du chauffage actuel.

J'ai aussi cité le fait qu'on commence à sentir, dans certains pays et dans certaines classes—naturellement, uniquement dans les pays industrialisés—une certaine saturation de besoins.

J'ai enfin aussi insisté sur le fait que l'activité industrielle va de plus en plus vers des activités qui consomment moins d'énergie qu'autrefois, ou vers des services.

Donc, notre contribution, tout en étant très cohérente avec celle des deux autres groupes, va vers la constatation qui est que, automatiquement, et ceci est très important, la consommation en l'an 2000, malgré une très forte augmentation des pays sous-développés, ne sera pas celle que l'on a coutume de donner, c'est-à-dire 4,5,6, 10 fois la consommation d'aujourd'hui, mais peut-être 2, sûrement inférieure à 3.

MUNDLAK: Economic group. If I am not wrong in listening, I think that in the final points that were selected the growth of population was not mentioned. I think this was mentioned in the conclusions of the economic group and I do not think that a conference like this can come up with the conclusion without at least mentioning that the excessively high rate of population is the cause, in the dynamic sense, for scarcity. I would also recommend that we go for a stronger statement and consider it as endogenous in the system and call for a decrease in the rate of population growth. But at least in the exogenous sense I think there should be a common agreement on this point.

COULOMB: Je ne suis pas sûr que nous puissions discuter vraiment le terrible problème de la population. Nous n'avons pas formé de groupe pour s'en occuper. Nous avons seulement eu l'exposé de Monsieur Tabah. Nous savons que c'est une question extrêmement importante, mais il faut la remettre à la conférence suivante. Cependant, si quelqu'un veut en parler, je lui donnerai la parole.

BROWN: I believe that the problem of rapid population growth was discussed in virtually all of the groups and if you will remember, recommendation number 3 of the working group on long range mineral resources stated the following: the rate of population growth worldwide should be decreased. It just happens that this was not selected as an item for discussion, but if approved I would assume that this would go into the record of the conference as a recommendation.

COULOMB: La raison pour laquelle je n'ai pas cru devoir laisser discuter ce sujet n'est pas son manque d'importance, mais uniquement le sentiment que nous n'étions pas en mesure de le faire utilement.

L'exposé de Monsieur Tabah n'a pas été un exposé contradictoire et nous ne pouvons guère prendre parti. Mais le groupe a pris parti et, naturellement il en sera fait mention dans la publication des discussions intérieures au groupe.

HORVAT: I should like to review the main conclusions of all the groups, as you selected them, from a somewhat different point of view. The first suggestion was to concentrate on the quality of life. My question is: Who has been against the quality of life so far and who could be, in his right frame of mind, against the quality of life? Particularly when one has in mind that it includes abundances as one of its elements as one of our colleagues has very correctly pointed in the other way. So it is certainly not the unawareness that the quality of life is unimportant that we have had a rather miserable life so far, but there must have been some other reasons. And these are not technical. The second suggestion by the economists was that this distribution should take place before growth on the global scale. I am a little bit skeptical about this, but suppose it is correct. The question is, How should it be done? Today, the distribution has not even been resolved within national boundaries; there are tremendous differences between rich and poor. How are you going to do that? The rate of growth should increase in less-developed countries. One is bound to ask the following question: In order to achieve this, you have to have planning on the national scale, and in order to accelerate this in underdeveloped countries, you have to have planning on the international scale. How do you do it? Regarding the fourth suggestion one may ask why these methods have not already been developed or the research intensified since we know more or less what the promising alliances were of research? It is clear that if only a fraction of military expenditures were diverted to these purposes we should have been much better off today than we are. The fifth suggestion was that it is desirable to have global management of soil and water. I would say that in many countries, in most countries of the world, we do not have management of natural resources—and water and soil in particular—at the national level. However, how are we going to achieve that at the international level? The aim of our conference, or the subject of our conference has been for a plan of action. We have been discussing the limits of growth. From the results of our discussion it seems to be rather clear that these limits are not technical, but social and political. So the final

conclusion, I believe, that I somehow found in your enumeration of all the basic conclusions of our discussion, should probably be that there is no place for pessimism regarding the technical possibilities of solving the problems in front of humanity. But whether they will be solved or not depends exclusively on social relationships and political decision making.

COULOMB: Je vous remercie beaucoup, mais je suis un peu en peine pour savoir à qui passer la parole, parce que vous avez touché à beaucoup de sujets. Quelqu'un peut-il répondre à l'un des points qui ont été soulevés? Monsieur Aubert, pensez-vous pouvoir répondre?

AUBERT: C'est assez simple. Je pense ne pas être tout à fait d'accord avec Monsieur Horvat sur ce point, que je connais un peu, de l'aménagement et de l'utilisation des sols. Il y a quand même un grand effort qui est déjà fait dans ce sens dans un certain nombre de pays, aussi bien dans des pays en voie de développement, comme la Côte d'Ivoire puisque j'ai personnellement participé pendant plusieurs années au très gros programme établi dans ce sens dans toute la partie forestière de la Côte d'Ivoire, sur la demande du gouvernement de ce pays, que dans des pays industrialisés comme la France, où l'on établit actuellement un plan d'aménagement des forêts et des bois et qui porte particulièrement, sous le contrôle du gouvernement, sur toutes les forêts privées. Par conséquent, je crois qu'il ne faut pas être aussi pessimiste peut-être que l'était Monsieur Horvat. Il est possible, peut-être pas sur un plan international, mais sur un plan national, de prévoir un meilleur aménagement pour une utilisation meilleure sinon optimale des terres.

COULOMB: Je dois préciser que le groupe n'a pas réclamé de plan mondial. Il a réclamé un plan d'aménagement pour les espaces naturels et les eaux; l'accent a été mis sur la considération simultanée des deux problèmes. Mais le groupe n'a pas décidé si cette confrontation entre les différents sites devait être faite à l'échelon régional, à l'échelon national, à l'échelon international, ou mondial.

BROWN: The problems confronting the world today are political and social in nature but with strong technological overtones. Technological change has created many of these problems. Technological change can be necessary but by no means sufficient in the solution. I think you have more confidence in the scientist and technologist than I have in his being able to solve the technological components of these problems, and even the technological solution involves social and political factors. There must be research allocations, which means that the people who make decisions in our various ministeries and so forth have to understand the problems, have to take a sufficiently long range view so that they will budget the necessary research and development that has to be done.

COULOMB: La parole est à Monsieur Cloud.

CLOUD: First of all I would like to congratulate you and your associates on the dispatch with which you have gotten to the central questions and the recommendations and suggestions presented. I find them all very good and I can take exception to only one general conclusion, that is the one offered by the energy group that sees a saturation in energy needs leading to a slowing down of energy requirements to about only two times the present by the year 2000. That would be true if we did not have to look forward to a large increase in the investments of energy needed to increase mineral production in order to achieve the desired gains in the economic growth of developing countries.

However, in these recommendations that are selected for central attention, I miss two things. I should like to preface my mention of these two things by observing that we are a group of scholars and humanists. We in this group are not politicians; we obviously have no power to implement any political action. It may be that the politicians will choose to reject all of the proposals we have to make, but it seems to me that we have a duty as scholars and humanists to tell the politicians what we really believe. So I have two additional things that I would like to urge upon you as resolutions of the group. If you do not choose to accept them as resolutions, I would like then to call for a show of hands on each of these resolutions. I am not proposing that we go into long discussions about them. We have had a certain amount of discussion about this and I should just like to know who now, at the present time, knowing what they do, would be for and against these propositions.

I refer to the things which are on the last page of a thing which I have written up and which is available in the front of the room for those of you who do not have it; it is a page called "Toward equity and balance" and I am referring to the very last item on that page 2 at the bottom of the page. A second one is on the page called "Toward the protection of life". I am referring to the first recommendation, the beginning of the second paragraph. I had the opportunity to elaborate my views about this a little more this morning and I shall not presume further on your time. I think it has been discussed, not only fairly extensively in some of the sections, but by many of us repeatedly in other circumstances. It becomes very clear that if Mr. Horvat's hopes and expectations for the ability of man to solve his problems is to be realized, that the population issue is one of the most serious issues confronting us in the context of our present discussion. This is so, among other reasons, because the whole picture of mineral resource availability really depends on what the levels of consumption will be and how many consumers there are likely to be. Population increases, we have seen repeatedly, wipe out gains that are made in technology, food production, mineral production, and so forth. So I would like to move proposition number 2 at the bottom of the page, "Toward equity and balance", and see what kind of an expression of support or opposition we get to this motion from the floor. I should like then to recommend that the nations and private enterprises of the world discontinue further efforts to develop breeder reactors or other devices that use and generate substanti

quantities of plutonium-239 or any product approaching the potentialities of plutonium-239 for the destruction of life. May I call for a show of hands on these two resolutions?

COULOMB: Je pense que la réponse, pour la deuxième résolution qui est la plus importante, va vous être donnée par Monsieur Gibrat, parlant au nom du groupe qui s'occupe de l'énergie. Monsieur Gibrat?

GIBRAT: Deux questions ont été posées au groupe de l'énergie. La première, c'est la mise en question de ce que nous avons pensé, à savoir que les mécanismes de réduction automatique conduiront, en l'an 2000, à une consommation qui sera comprise entre deux et trois fois la consommation actuelle. Cela résulte d'études très approfondies. Ces études ont pris en compte ce qui n'est qu'un détail, à savoir l'augmentation de consommation d'énergie éventuelle, par suite des ressources minérales. Je ne crois donc pas que nous puissions en séance, sans avoir d'autres chiffres, modifier une opinion, que je pense, pour mon compte, parfaitement fondée.

Deuxième question: les nations, à l'heure actuelle et les entreprises privées, devraient stopper les efforts pour développer le réacteur surgénérateur, et autres projets' engendrant le plutonium. Ceci a deux aspects. Nous avons traité, au groupe de l'énergie, l'aspect que je considère comme fondamental, que j'ai rappelé tout à l'heure, à savoir que, en cas de prolifération de ce type de réacteur, des problèmes importants s'élèveraient. Ceux d'entre vous qui, en assemblée générale, ont assisté à la réunion d'avant-hier matin se rappellent que j'ai donné en particulier comme exemple les problèmes de violence.

Là où nous divergeons, c'est qu'il estime qu'il faut commencer dès aujourd'hui, je dirais même dès hier, car il n'ignore pas que tous les réacteurs actuellement en fonctionnement sont aussi des producteurs de plutonium, ce qui n'est pas très réaliste d'autant plus que ceux-ci fonctionnent depuis fort longtemps. A ma connaissance, il n'y a jamais eu, avec les reacteurs actuels, le moindre incident concernant le plutonium. Cela n'enlève rien à ma proposition d'intensifier, au contraire, dès maintenant, très fortement, l'étude des sources nouvelles, pour être certain, le jour où la prolifération de ces usines deviendrait importante, d'avoir un moyen de substitution.

COULOMB: Je remercie Monsieur Gibrat, et je vois que la différence de positions entre Monsieur Cloud et Monsieur Gibrat n'est pas aussi grande qu'elle pouvait l'être au départ. Monsieur Cloud voudrait qu'on dise dès maintenant: "jamais de breeders à cause du plutonium", et Monsieur Gibrat dit que nous devons déterminer le plus vite possible la probabilité d'un accident. Le groupe a été, je crois, d'accord avec Monsieur Gibrat, sur cette position: pousser les études au maximum, de manière à être prêts au moment où les surgénérateurs qui en sont au stade des essais devraient passer au stade d'exécution.

Le second point soulevé par Monsieur Cloud (le premier dont il ait parlé) est la réduction de la population. Comme je l'ai dit tout à l'heure, c'est en effet un problème capital, mais je me demande si la présente conférence peut vraiment s'en occuper. Je répète que nous avons demandé à Monsieur Tabah de nous en parler. Il l'a fait longuement. Il nous a expliqué ce qui a été fait à la conférence de Bucarest. Je crains que nous ne puissions pas aller plus loin. Si nous avons encore le temps (entre 6 h et 6 h 30), au moment où je donnerai la parole pour les résolutions autres que celles qui correspondent aux travaux des commissions, je veux bien qu'on revienne sur les deux propositions de Monsieur Cloud. Je dois lui dire cependant qu'il ne serait, à ce moment-là, que le 3ème sur ma liste parce que j'ai déjà deux personnes qui m'ont demandé à parler après 18 heures.

CLOUD: Mr. Chairman, could we just take 30 seconds, not to press a resolution, but to get a sense of the congress here. Can I ask for a show of hands as to those who see plutonium-239 as a really dreadful problem?

COULOMB: Trois personnes ont demandé la parole sur votre intervention. Je vais la leur donner mais en les priant d'être brefs parcé que j'ai encore beaucoup de noms sur ma liste. Voudriez-vous vous nommer, s'il vous plaît, et parler uniquement sur le point soulevé par Monsieur Cloud.

BRENDOW: I want to comment on the procedure proposal that precedes some kind of voting. As I understood your proposal, we will not decide in plenary on any resolutions, but this would be the opinion of the chairmen of the various groups. So I do not see any real usefulness in passing some kind of vote. Should you, nevertheless, decide to go on a vote, I cannot engage my organization and I would not be in a position to vote on anything. Let me just say that I think that once we have the conclusions in writing at home we can work on it we would be in a better position to judge.

COULOMB: Je dis tout de suite que nous ne voterons sur aucune espèce de résolution; il ne sera demandé à personne d'engager quelque organisation que ce soit. Ce que les groupes ont indiqué comme étant leur avis, sera publié comme étant l'avis des groupes. Mais je serais heureux si, sur les points sélectionnés, nous pouvions dégager une opinion générale des personnes présentes.

SIKKA: I am not clear as to what reduction the underdeveloped countries can affect in the consumption of food and minerals as suggested in the resolution as they are already living on a subsistence level. But I do share Dr. Cloud's concern about the breeder reactors. But I do not think we can vote at this stage. Maybe later on.

LEWIS: I offered to speak on plutonium at a previous session but the time did not arise. The trouble is the statements made here about plutonium are not correct. There is a deliberate campaign, which is highly dangerous to the world, fostering a fear of plutonium. I would say that this is something not unknown in

the world. The late Justice Oliver Wendell Holmes gave a famous decision saying that a man could not claim freedom of speech to rise up in a crowded auditorium and shout, "Fire!" The point is there is no risk of fire. The fear is of mob panic. This is the situation with plutonium. The fear of mob panic is real. The fear of plutonium is not real. We operate, as Mr. Gibrat has said, very safely with plutonium. We know it is permissible to have one-tenth of a microgram fixed in the human body. We believe that we can keep working at that level. I am speaking of workers who are much more exposed than anyone in the outside population is. This is a fixed, permissible body burden. It is not a lethal dose. Nobody knows what a lethal dose for a human being of plutonium really is.

ABRAMOWITZ: I should like to see what I can do to throw a little light on what the Chairman and others found in the conclusions of the long range minerals group as well as on the views expressed by Mr. Brown and those that were expressed on behalf of the economists by M. Malinvaud. I hope also that what I can say may bear on the intervention of Mr. Horvat. I think I ought to start by saying something about the set of assumptions which were in the minds of the economists in the discussions that we held within our group. It is fair to say that we started first and foremost from the very sharp awareness of the poverty and extreme difficulty of life in the poor countries. We also had in mind the conditions of poor people, even in the rich countries of the world. Although a great deal may be done by redistribution of income within the richest countries, to raise the standard of living of poor people, such redistribution is very hard to bring about as Horvat has emphasized. I think that was one of the facts that we recognized in drawing up our own conclusions. Furthermore, as between rich and poor countries, it is perfectly clear that redistribution alone would hardly begin to touch the problem because of the huge magnitude of the populations of the poor countries and the very low levels of income in those countries today. So a rise in production and productivity in the poor countries is utterly essential. Once one has recognized that, it becomes important also to recognize that the possibility of such an increase in productivity and production within the poor countries is also dependent upon what is happening in rich countries and upon the possibilities that they have for raising their own levels of output, because the poor countries are very dependent on the rich countries both for a flow of capital for aid to their balance of payments and for grants in kind. Now for all these reasons we were very hesitant to sct as a target, even though we were extremely sensitive to the problems of scarcity of resources and energies, a reduction in growth rates of output in the richer countries of the world. But we *do* recognize that such a reduction might be forced upon richer countries and perhaps upon all the countries of the world by scarcities if those turn out to be more obstinate than some of us might hope. Hence, when we came to write our conclusions, we expressed them in a less direct way than did the group dealing with long rangc mincral resourccs. We spokc about managing resources with a certain prudcnce and a certain caution, having regard to scarcities and constraints as they might appear and with regard to what the necessities of the future might be. If, indeed, those scarcities turn out to be very severe, then a question comes up about the distribution of the burden. Here, it seems to me, that our chairman may have failed to catch a little bit of the flavor of point 5, which I translate somewhat in the following way: that the problem of achieving an equilibrium between resources and needs poses the danger that this will create greater burdens for the poor countries of the world than it does for the richer countries of the world or for the world as a whole. So the policy of growth of the rich countries has to be guided by this consideration.

JOY: Referring to the long term view of these global models, I scem to have the impression that all those concerned with the economics and the modeling, as well as with the resources and the energy needs, are not satisfied with their ability to put all the coherent data together. Therefore, following your own indications and your request for something practical along the lines which you referred to as institutionalization, I would like to propose that we contrive a group to conduct a pilot study on an interdisciplinary and international basis of a single problem. In order to ensure that results are got within a reasonable time it would be worthwhile to assess the feasibility of a complete, thorough pilot study on a not too complicated commodity industry in a not too large country. If it is possible to get together a number of people who could help with the actual practical work, from among the economists, energy specialists, resource specialists present, then I would be quite prepared to discuss with the Department of Industry in the United Kingdom and see what we could do to help.

COULOMB: Je vous remercie d'avoir adopté un point de vue pratique, et je demande à Monsieur Davous s'il peut commenter très brièvement votre proposition.

DAVOUS: Je suis parfaitement d'accord sur ce qui vient d'être dit sur l'importance de mettre quelque chose de concret sous le terme multidisciplinaire. C'est très joli de dire "on va créer des équipes multidisciplinaires pour les problèmes." Si j'ai bien compris la recommandation, c'est de dire qu'on en fasse déjà au moins une, internationale, multidisciplinaire, sur un problème concret, et, à ce moment-là, ce sera déjà un premier pas peut-être valable.

Dans la recommandation du groupe modélisation, relative à la coopération internationale, ce problème n'a pas été discuté en détail. Il a simplement été dit que les implications des autres recommandations semblaient nécessiter l'existence d'un certain organisme de coordination. La nature exacte de cet organisme n'a absolument pas été discutée. Si je lis à travers les débats, je comprends qu'il y a une certaine tendance à voir dans cet organisme quelque chose d'assez léger—le Professeur Moiseev, par exemple, ce matin, a employé

qui consisterait à minimiser la consommation d'énergie. Le groupe des économistes n'est pas intervenu sur ces idées, mais il s'est quelque peu concerté à leur sujet. Il doit se déclarer assez opposé à une interprétation littérale de ce que vous proposez. Sans doute n'avons-nous pas d'objections à ce que l'on calcule le contenu en énergie des différentes productions. Nous pensons même que simultanément, on pourrait tout aussi bien calculer précisément le contenu en travail. Cette information est toujours utile. Mais nous ne pouvons pas proposer une politique dans laquelle on chercherait délibérément à orienter les productions en se donnant pour seul objectif l'économie d'énergie et en négligeant le travail qui reste, à l'heure actuelle, une ressource plus précieuse que l'énergie. Il faut certes économiser l'énergie maintenant; mais il ne faut pas que ce soit la seule considération qui motive nos choix.

BOL ALIMA: Je me permettrai tout d'abord de remercier tous les représentants des différents groupes de travail, car au début, j'étais plutôt inquiet, ne croyant pas que nous pourrions facilement arriver à une synthèse aussi brillante des différents débats qui ont eu lieu au cours des colloques et des séances plénières. Mon inquiétude, je dois l'avouer était surtout fondée sur le fait que la composition de notre Assemblée pouvait faire oublier les problèmes d'une partie de l'Humanité et que le Plan d'Actions que nous étions conviés à élaborer ne serait qu'un Plan pour une certaine Humanité. . .

Mais je dois avouer que nos recommandations et nos résolutions n'ignorent pas les problèmes des économies en développement et des Pays sous-équipés, quoique l'unanimité n'ait pas été obtenue chaque fois, ce qui est d'ailleurs normal.

Cela étant dit, ma question va concerner particulièrement le problème des analyses des systèmes et des modélisations.

Je reconnais que, pour une planification à court terme, et cela se comprend d'ailleurs pour un ressortissant d'un pays pauvre comme le mien, des méthodes de prévisions sont nécessaires pour rendre moins incertain l'environnement économique et social.

En ce qui concerne les prévisions et les modèles à long terme, il y a tout de même quelques réserves qu'il convient peut-être de mentionner. Je crois d'ailleurs que le groupe qui a travaillé sur les problèmes des modèles a clairement exprimé que, lorsqu'on dépassait les systèmes physiques et qu'on voulait y intégrer les paramètres biologiques et, encore plus, humains, les problèmes étaient plus délicats.

Quand il est donc question d'une coopération internationale qui pourrait se faire éventuellement par le canal d'un organisme qui, comme venait de le dire tout à l'heure le représentant du groupe, Monsieur Davous, s'occuperait probablement au moins d'élaborer les programmes, on peut se demander sur quoi porteraient ces programmes. Je ne le sais pas car, en fait, que ce soit des programmes ou des modèles, il faudrait partir d'un certain nombre d'actions, d'une certaine conception de l'homme, d'une certaine conception de l'évolution de l'humanité, et je ne pense pas que, sur ce point, il y ait déjà unanimité sur le plan de la conception, sur le plan de l'éthique que l'on veut avoir de l'humanité, afin de pouvoir élaborer peut-être des programmes mondiaux, et encore moins des modèles mondiaux.

Je ne sais pas si on ne pourrait pas reformuler quelque peu cette recommandation, car tout en recommandant la nécessité d'une coopération internationale dans ce domaine, il faudrait considérer l'organisme qui pourrait être créé comme un organisme travaillant quelque peu à la demande. Ainsi un groupe d'Etats ou un Etat donné ayant défini lui-même ses objectifs—car les modèles ne diront que des choses en rapport avec l'éthique propre de ceux qui leur auront fourni les paramètres composants—pourrait s'adresser à cet organisme international afin de solliciter l'aide nécessaire à l'élaboration d'une prospective partant ainsi des données propres à un groupe donné.

Le danger serait en effet grand de travailler sur des modèles quasi standard ne correspondant à aucune philosophie propre, car on risquerait alors d'avoir des modèles tendant à imposer des types de sociétés que tout le monde n'approuve pas nécessairement.

COULOMB: Vos remarques sont tout à fait pertinentes et je pense que l'Institut de la Vie, qui devra trancher en dernier ressort, en tiendra le plus grand compte. Je passe la parole maintenant à Monsieur Michiels.

MICHIELS: Les problèmes dont l'étude est abordée au cours de cette conférence sont fortement liés au développement de l'industrie—celle-ci étant comprise dans son sens le plus large de toute l'activité de production de biens et services. Il faut en effet reconnaître que c'est à l'industrie qu'incombera la concrétisation du plan d'actions. D'autre part, son expérience de l'action est irremplaçable pour l'établissement de calendriers et de programmes techniques et financiers réalistes. Certains représentants des milieux industriels—et qui m'ont demandé d'être leur porte-parole—ont eu leprivilège d'apporter leur collaboration active à l'étude des cinq thèmes de ce congrès et aux discussions plénières. Ils en ont retiré l'impression que l'apport des compétences de l'industrie pourrait être encore plus important et ils tiennent à assurer l'Institut de la Vie de leur collaboration la plus large à ses travaux futurs. Ainsi que l'ont proposé plusieurs autres congressistes, nous croyons en la nécessité de créer, avec la participation de l'industrie, un groupe interdisciplinaire qui aurait pour thème les problèmes techniques et financiers et les calendriers associés.

COULOMB: Voilà encore une proposition précise et pratique. L'Institut de la Vie en tiendra sans doute le plus grand compte. Ce serait maintenant le tour de Monsieur Piore, qui avait demandé la parole mais il est parti.

MARCHAND: Vous avez déclaré, à deux reprises, Monsieur le Président, que nous ne devions pas mentionner le problème démographique dans nos recommandations globales. Je ne suis pas tout à fait d'accord avec ceci, et pour deux raisons.

1° Ce problème a effectivement figuré à maintes reprises dans nos discussions.
2° Et ceci, je pense, est très important; un plan d'action pour l'humanité, qui demeurerait silencieux sur ce problème très important, peut-être le plus important de tous, serait sérieusement déficitaire et sa crédibilité en souffrirait énormément.
Au minimum, il faudrait au moins mentionner que nous avons été saisis, de la part des Nations Unies, de ce sujet et que nous lui donnons tout l'appui moral qu'il mérite.

COULOMB: Pris sous cette dernière forme, c'est tout à fait exact. Monsieur Tabah nous a mis au courant de ce qui s'est passé à la conférence, et nous pouvons rendre à cette conférence l'hommage qu'elle mérite.

ROSS: In going through my notes of points worth remembering I have found two that are relevant to the subjects picked out by the Chairman. It was proved to us in the Minerals Group that the question of the supply of minerals and of water is the same question as the price of energy. We had another contribution to the effect that the price mechanism and the free market has not succeeded in achieving a fair distribution of energy. The price of energy has been too low to the man who wishes to heat or cool his inadequately insulated house. It is now too high for India to buy fertilizers and fuel for tractors and irrigation pumps. Obviously we need differential pricing of energy in some way. We have been told we cannot solve problems on an international scale until they have been solved on a regional scale. So what is the local solution? In Britain, if I wish to buy diesel oil for a vehicle on the road it is expensive because of a heavy tax. If I buy the same oil for my fishing boat, or for the tractor on my farm, it is cheaper because there is no tax. It seems to me that there should be some kind of international taxing system on such lines.

Finally, Sir, may I give this Conference a motto? "To be uncertain is to be uncomfortable. But to be certain is to be ridiculous."

COULOMB: Je reconnais bien l'humour anglais et je vous remercie. La réglementation internationale des taxes pourra être dite internationale même si elle ne s'applique qu'aux pays capitalistes, mais les pays de l'Est n'accepteront certainement pas d'entrer dans des voies pareilles. Quelqu'un demande -t-il encore la parole sur les rapports des différents groupes? Sinon, nous passons aux autres propositions. Le premier à avoir demandé la parole est Monsieur Guy Berman, Ingénieur des Mines.

BERMAN: Les conclusions des différents groupes contiennent en particulier la notion de qualité de la vie. Cependant celle-ci n'a pas été expressément définie; le terme "bonheur", qui recouvre à mon avis une notion très importante, et pas tout à fait semblable à celle de "qualité de la vie", n'a pas non plus été prononcé.

Monsieur Bol Alima tout à l'heure, en particulier, a souligné que le bonheur était extrêmement différent pour les différents peuples, et que les projets internationaux devaient tenir compte de cette différence.

Il me semblerait donc utile d'inclure dans les résolutions de la conférence, ou peut-être de considérer comme sujet d'une prochaine conférence, l'étude de la qualité de la vie; en particulier, comment la prendre en compte dans les décisions économiques de gestion et d'allocation des ressources, ou dans des modèles qui restent actuellement, nous a dit M. Davous, essentiellement quantitatifs.

COULOMB: Bien entendu, la définition de la qualité de la vie et la définition du bonheur sont des questions extrêmement importantes. Je ne pense pas que nous puissions les traiter en quelques minutes. Il y a prochainement, à Londres, une réunion sous les auspices de la Fondation internationale de la Culture où l'on doit discuter précisément de ses aspects éthiques: le bonheur sera à l'ordre du jour. Nous aurons peut-être à nous inspirer de ce qui se dira dans cette réunion. Personnellement, je ne crois pas que la notion de bonheur soit une notion simple. En gros, il y a deux espèces de bonheur: l'acquisition des biens et la satisfaction du devoir accompli, mais je ne veux pas en dire plus. Comme vous dites, il faudrait une autre conférence, mais ce ne sera peut-être pas une conférence de l'Institut de la Vie.

DALKEY: One small remark to perhaps make us feel a little better. The notion of happiness, the quality of life, was not absolutely ignored by the conference. There was one paper in the modeling session dealing with the latest research on measuring individual happiness and also dealing with the possibilities of dealing with social value functions using that type of research. It was small, but not absolutely infinitesimal.

LEWIS: Just a very small point, but I think important. There was a very considerable contribution to the energy section, by Dr. Kellogg who, I think, is not here now on climatology. It was pointed out that climatic change is quite characteristic of the world. We are at present in a considerable change of weather. We do not know whether we can expect this to stabilize or to get worse. So it seems that we should encourage, in order that mankind can have a little anticipation, encourage to the maximum studies of changes of climate.

STEWART: Less than a month ago there finished a major conference in Sweden organized through the Global Atmospheric Research Program, on the question of climate and climate modeling. There are committees formed by several different organizations for looking at the questions of change of climate, the stability of climate, and the degree to which climate may be predictable. Attention has already been drawn to this subject and it is being closely looked at by those who are best fitted to look at it. It is by no means

being neglected. This group could add its recommendations if it wishes, but it should not assume that the topic is being neglected.

COLON: These last days I spoke with different colleagues from different countries present here. I found that there was a good consensus in what has to be done after this conference closes. We came to a draft of final resolutions and I would like to present them to you:

1. The themes discussed by the conference: economics, energy, natural resources and recycling, biological equilibria, modeling, have a major and permanent interest for mankind. The quality of the participants in different disciplines guarantees the high scientific value of the conclusions.
2. These conclusions should be brought to the attention of all governments of the world and intergovernmental organizations. Thus a link would be established between objective science and men of responsibility.
3. The initiative of Institut de la Vie should be pursued at two levels:

— scientific reflexion;
— relationship with those institutions responsible for life of men and the society.

4. To assure the continuity, it would be appropriate that Institut de la Vie:
(a) pursues the organization of the scientific deliberation in several ways:
(i) establishment of a committee with specialized and multidisciplinary sections;
(ii) organization of a new conference within four years;
(iii) encouraging existing scientific programs and/or instituting new programs;
(b) maintains the dialogue at the most influencial levels.

Traduction française:

1. Les thèmes traités par la conférence: économie, énergie, ressources naturelles, équilibres biologiques et environnement, modélisation, ont un intérêt majeur permanent pour l'humanité. La qualité des participants des différentes disciplines garantit la haute valeur scientifique des conclusions.
2. Ces conclusions devraient être portées à la connaissance de tous les gouvernements du monde et des institutions intergouvernementales. Ainsi serait établi un lien entre la science objective et les hommes à responsabilité.
3. L'initiative de l'Institut de la Vie mérite d'être développée dans deux voies:
—. La réflexion scientifique.
—. Les relations avec les institutions responsables de la vie des hommes et de la société.
4. Pour assurer cette continuité, il conviendrait que l'Institut de la Vie:

— poursuive la réflexion scientifique par:
. la constitution d'un comité permanent
. l'organisation périodique de sessions spécialisées et de réunions communes interdisciplinaires
. l'organisation d'une nouvelle conférence dans quatre ans
. l'encouragement à des programmes scientifiques existants ou la mise en oeuvre de programmes scientifiques nouveaux,
— et maintienne le dialogue avec les centres de décision.

COULOMB: Bien sûr il y a quelque difficulté à cerner les conclusions de cette conférence. Elles comprennent d'abord les résolutions des groupes, et nous avons eu une discussion qui les a éclairées. Nous avons maintenant devant nous l'organisation qui a convoqué notre réunion et qui est l'Institut de la Vie. En réalité, votre proposition s'adresse à l'Institut de la Vie, à qui nous avons fait nous-mêmes un certain nombre de suggestions. Les conclusions que l'Institut de la Vie pourra communiquer, s'il le désire, aux Gouvernements ou aux Organisations internationales, seront arrêtées par lui, à la lumière des documents établis par les groupes, et de nos discussions. Comme nous avons dit que nous ne voterions pas, nous ne pourrons pas demander qu'on transmette notre opinion, mais l'Institut de la Vie, ayant pris conscience des problèmes et connaissant l'importance relative des différentes questions, peut dire aux Gouvernements comme aux grandes Organisations internationales ce qu'il a trouvé dans cette conférence. Sous cette réserve de forme, je ne vois pas personnellement d'objection à ce que vous venez de proposer.

Nos travaux sout finis. Je vous remercie de tout cœur.

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